Total Maximum Daily Loads for Fecal Pathogens in Buffalo Bayou and Whiteoak Bayou

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FINAL REPORT

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TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION 1

CHAPTER 2 STAKEHOLDER/PUBLIC EDUCATION AND INVOLVEMENT 4

2.1 SUMMARY OF SUPPORT ACTIVITIES 4

2.2 TECHNICAL PRESENTATIONS AT STAKEHOLDER MEETINGS 4

CHAPTER 3 ASSESSMENT OF BIOSOLIDS RELEASES 5

3.1 BIOSOLIDS SELF-REPORTING DATA 6

3.2 BIOSOLID GENERATION FACTOR METHOD 8

3.3 SOLIDS MASS BALANCE METHOD 15

3.3.2 THICKENING 21

3.3.3 AEROBIC DIGESTERS 22

3.3.4 DEWATERING AND BELT PRESSING 22

3.3.5 TOTAL SLUDGE GENERATION 23

3.3.6 UNCERTAINTY IN SLUDGE ESTIMATION USING MASS BALANCE APPROACH 24

CHAPTER 4 WATER WITHDRAWALS AND DIVERSIONS 34

4.1 REGION H WATER AVAILABILITY MODEL (WAM) 34

4.2 WATER RIGHTS IN BUFFALO AND WHITEOAK BAYOUS 38

4.3 IMPACT OF WWTP FLOW REDUCTIONS UNDER DIFFERENT STREAM FLOW AND SEASONAL CONDITIONS 45

4.3.1 IRRIGATION USE 45

4.3.2 INDUSTRIAL USE 45

4.3.3 DOMESTIC USE 46
4.4 MODELING OF DRY WEATHER CONDITIONS 46
4.5 HSPF ASSESSMENT OF WATER WITHDRAWALS 47
CHAPTER 5 SEDIMENT CONTRIBUTIONS 49
5.1 LITERATURE AND LOCAL DATA 49
5.1.1 LITERATURE REVIEW 51
5.1.2 HCFCD SAMPLING RESULTS 51
5.2 WWTP EFFECTS ON STREAM SEDIMENTS 54
5.3 SETTLING TESTS 61
5.4 DISCUSSION 71
CHAPTER 6 LEVELS OF EC IN ADDICKS AND BARKER RESERVOIRS 72
6.1. RESERVOIR OPERATION 72
6.2. DRY WEATHER RESERVOIR SAMPLING 76
6.3 WET WEATHER RESERVOIR SAMPLING 81
6.3.1 WET WEATHER EVENT 1 82
6.3.2 WET WEATHER EVENT 2 89
6.3.3 WET WEATHER EVENT 3 97
6.4 LOAD CALCULATIONS 108
CHAPTER 7 QUANTIFICATION OF BACTERIA LOADS FROM 120
OVERFLOWS AND BYPASSES 120
7.1 WWTP BYPASSES 120
7.2 DRY WEATHER SANITARY SEWER OVERFLOWS (SSOs) 121

7.2.1 SUMMARY OF COH SSO EXCURSION DATA 122

7.2.2 COH SSO EXCURSIONS WITHIN BUFFALO BAYOU AND WHITE OAK BAYOU WATERSHEDS 123

7.2.3 ESTIMATION OF SSO FLOWS AND EC LOADS 123

7.2.4 POTENTIAL OF SSOS TO REACH BAYOUS 128

7.3 WET WEATHER FACILITY DATA ANALYSIS 132

CHAPTER 8 ASSESSMENT OF *E. COLI* DOWNSTREAM OF WASTEWATER TREATMENT PLANT OUTFALLS 146

CHAPTER 9 BACTERIA SOURCE TRACKING 154

9.1 SOURCE SAMPLING 156

9.2 *E. coli* ISOLATIONS 159

9.3 SOURCE ANTIBIOTIC RESISTANCE ANALYSIS 163

9.3.1 TWO-WAY CLASSIFICATION (HUMAN VS. NON-HUMAN) . . . 167

9.3.2 FOUR-WAY CLASSIFICATION: HUMAN VS. WILDLIFE (BIRD/BAT) VS. LIVESTOCK (HORSE/COW) VS. PET (DOG) . . . 169

9.3.3 SIX-WAY CLASSIFICATIONS: BIRD VS. COW VS. DOG VS. HORSE VS. BAT VS. HUMAN 171

9.3.4 ARA DISCUSSION 171

9.4 SOURCE PULSE FIELD GEL ELECTROPHORESIS 175

9.4.1 MOLECULAR DATABASE 177

9.5 UNKNOWN SOURCE SAMPLING 181

CHAPTER 10 HSPF MODEL EXPANSION 184

10.1 WWTP TIME-VARYING FLOW 185
10.1.1 SUMMARY OF CITY OF HOUSTON WWTP DAILY DISCHARGE FLOWS 186
10.1.2 DEVELOPMENT OF CONVERSION FACTORS 190
10.1.3 USE OF CONVERSION FACTORS TO DEVELOP TIME SERIES . 196
10.1.5 ANALYSIS OF TIME-VARYING FLOW (TVF) OUTPUTS 197
10.2 DATA COLLECTION FOR NEW MODEL TIME PERIOD 202
10.2.1 MODEL SET-UP DATA 202
10.2.2 MODEL ASSESSMENT DATA 207
10.3 BUFFALO BAYOU MODEL EXPANSION 207
10.3.1 DATA COLLECTION - SUBWATERSHEDS AND HYDROLOGY . 213
10.3.2 METHODOLOGY FOR MODEL EXPANSION 219
10.3.3 DEVELOPMENT OF FTABLES FROM TSARP HEC-RAS MODELS 222
10.3.4 ADDICKS AND BARKER RESERVOIR GATE SIMULATION . . . 223
10.3.5 HYDROLOGIC CALIBRATION/VALIDATION 225
10.3.6 *E. COLI* CALIBRATION 239
10.4 WHITEOAK BAYOU MODEL 242
10.4.1 HYDROLOGIC CALIBRATION/VALIDATION 242
10.4.2 *E. COLI* CALIBRATION 251
CHAPTER 11 QUALITY ASSURANCE PROJECT PLAN AND QUALITY CONTROL . 257
11.1 QAPP 257

11.2 QUALITY CONTROL 257

11.2.1 FIELD QA/QC 258

11.2.2 LABORATORY QA/QC 259

CHAPTER 12 CONCLUSIONS AND FUTURE WORK 270

BIBLIOGRAPHY 276

APPENDIX A SLIDES FROM STAKEHOLDER MEETINGS

APPENDIX B COMPILATION OF WASTEWATER TREATMENT PLANT DATA FOR BIOSOLIDS

APPENDIX C MASS BALANCE CALCULATION SPREADSHEET

APPENDIX D ADDING A DIVERSION POINT AS AN ADDITIONAL EXIT IN HSPF

APPENDIX E SELECTED ANNOTATED BIBLIOGRAPHY OF SOILS AND BACTERIA

APPENDIX F BACTERIA SOURCE TRACKING

APPENDIX G ADDITIONAL ANALYSIS OF TIME VARYING FLOWS

APPENDIX H TIME-VARYING FLOW FOR ALL WWTPS IN THE STUDY AREA

APPENDIX I QUALITY ASSURANCE PROJECT PLAN

LIST OF TABLES

TABLE #	TITLE	PAGE #
Table 1.1	Description of Tasks Associated with Work Order 6	3
Table 3.1	Characteristics of Wastewater Treatment in Buffalo and Whiteoak Bayous	7
Table 3.2	Reported Biosolids	9
Table 3.3	Flow and Estimated Biosolids by BGF and Reported Biosolids	13
Table 3.4	Estimated Biosolids by Mass Balance Method (with Min and Max) and Reported Biosolids	25
Table 3.5	Estimated Biosolids by Mass Balance Method and by BGF Method	28
Table 3.6	Wastewater treatment plants Where Estimated Biosolids > Reported Biosolids	33
Table 4.1	Active Water Rights Permits	43
Table 5.1	Discharge Monitoring Report Data	56
Table 5.2	Sampling Data to Study Effects of Wwtp on Sediments	58
Table 5.3	Settling Test Data	64
Table 5.4	Field Data of Settling Test Samples	65
Table 6.1	Dry Weather Reservoir Water Quality Results	77
Table 6.2	Summary Statistics for Dry Weather Reservoir Sampling	78
Table 6.3	Statistics for Individual Stations - Dry Weather Sampling	80
Table 6.4	Wet Weather Reservoir Water Quality - Event 1	85
Table 6.5	Wet Weather Reservoir Water Quality - Event 2	92

Table 6.6 Wet Weather Reservoir Water Quality - Event 3 100

Table 6.7 Summary Statistics for Wet Weather Reservoir Sampling 106

Table 6.8 Statistics for Individual Stations - Wet Weather Sampling 107

Table 6.9 Bacteria and TSS Loads for Reservoir Sampling 109

Table 6.10 Summary Statistics for Bacteria Loads 110

Table 6.11 Individual Station Summary Statistics During Wet Weather 110

Table 6.12 Results of Targeted Reservoir Sampling 114

Table 6.13 Summary Statistics for Comparison of Pools to No Pools 116

Table 7.1 Estimation of SSO Excursion Flows 125

Table 7.2 Wastewater Sampling Data at City of Houston Facilities 127

Table 7.3 Potential of SSO To Reach Bayous Based on Destination Records 129

Table 7.4 Potential of SSO To Reach Bayous Based on Buffer Zones 133

Table 7.5 Northside Wet Weather Facility Data 136

Table 7.6 Belmont Wet Weather Facility Data 137

Table 7.7 Bretshire Wet Weather Facility Data 138

Table 7.8 Monitoring Data of Buffalo Bayou Upstream and Downstream of Northside Wet Weather Facility 139

Table 7.9 Monitoring Data of Brays Bayou Upstream and Downstream of Belmont Wet Weather Facility 140

Table 7.10 Monitoring Data of Halls Bayou Upstream and Downstream of Bretshire Wet Weather Facility 141

Table 7.11 Comparison Between Upstream and Downstream Sampling of Northside Wwf

(Using Data at 69th St Plant) 142

Table 7.12 Comparison Between Upstream and Downstream Sampling of Belmont Wwf 143

Table 7.13 Comparison Between Upstream and Downstream Sampling of Bretshire Wwf 144

Table 7.14 Comparison Between Upstream and Downstream Sampling of Northside Wwf (Using Data at Lockwood St) 145

Table 8.1 Field Measurements Collected during WWTP Outfall Sampling 149

Table 8.2 Laboratory Results for WWTP Outfall Sampling 151

Table 9.1 Animal sources used for the known source library 157

Table 9.2. Dates and locations of fecal sample collections 158

Table 9.3 Number of known source isolates obtained and confirmed as *E. coli* (>90%) . 162

Table 9.4 Number of known source isolates analyzed by Antibiotic Resistance Analysis (ARA) and Pulse Field Gel Electrophoresis (PFGE). 162

Table 9.5. Antibiotics used to establish antibiotic resistance profiles of known source *E. coli* isolates. 165

Table 9.6. Summary Table of Percent Average Rates of Correct Classification (ARCC) and Rates of Correct Classifications (RCC) for two (and three)-way classifications (Non-human vs. Human). 168

Table 9.7. Summary Table of Percent Average Rates of Correct Classification (ARCC) and Rates of Correct Classifications (RCC) for four-way classifications (Human vs. Wildlife vs. Livestock vs. Pet). 170

Table 9.8. Summary Table of Percent Average Rates of Correct Classification (ARCC) and Rates of Correct Classifications (RCC) for six-way classifications (Bird vs. Cow vs. Dog vs. Horse vs. Bat vs. Human). 172

Table 9.9 Numbers of *E. coli* isolates obtained and verified, for analysis Year 2. 183

Table 10.1.1 Summary Statistics for Daily Flow at City of Houston WWTPs for 2001 to 2004 (in MGD) 189

Table 10.1.2 Weekday Flow Conversion Factors 194

Table 10.1.3 Weekend Flow Conversion Factors 194

Table 10.1.4 Regression Analysis of TVF to Observed Daily Averages 199

Table 10.1.5 Comparison of Daily Volumes from City of Houston Plants to Volumes Estimated by TVF 199

Table 10.1.6 Comparison of WWTP 5-year Self-reported Averages and Simulated Time Varying Flows 200

Table 10.3.1 H-GAC LULC Categories and Assigned Impervious Percentages 216

Table 10.3.2 Channel Lengths for Areas Upstream of Addicks and Barker Dams 220

Table 10.3.3 Pervious and Impervious Areas for Areas Upstream of Addicks and Barker Dams 221

Table 10.3.4 Special Actions in HSPF to Simulate Closing and Opening of Reservoir Gates 226

Table 10.3.5 Selected Storm Events for HSPF Model Calibration and Validation 229

Table 10.3.6 Summary of Hydrologic Model Performance for Buffalo Bayou 230

Table 10.3.7 EC Model Performance Summary for Buffalo Bayou - Upstream of

Reservoir 240

Table 10.3.8 EC Model Performance Summary for Buffalo Bayou - Downstream of Reservoir 241

Table 10.4.1 Hydrology Model Performance Summary for Whiteoak Bayou 247

Table 10.4.2 EC Model Performance Summary for Whiteoak Bayou 253

Table 11.1 Field Equipment Blank Results 260

Table 11.2 Field Sample Split Results 261

Table 11.3 Field Sample Split Results - E. coli 263

Table 11.4 Laboratory Sterility Check Results 264

Table 11.5 Laboratory Duplicate Precision Results 266

LIST OF FIGURES

FIG #	TITLE	PAGE #
Figure 3.1	Generalized Schematic of Wastewater Treatment in Buffalo and Whiteoak Bayous	16
Figure 3.2	Relationship between Solids Retention Time and Yield Coefficient	19
Figure 3.3	Comparison of Estimated and Reported Biosolids (Flow < 1 MGD)	30
Figure 3.4	Comparison of Estimated and Reported Biosolids (Flow > 1 MGD)	30
Figure 4.1	Naturalized Flows at USGS Gage 08073500, Buffalo Bayou at Dairy Ashford Road	39
Figure 4.2	Naturalized Flows at USGS Gage 08074000, Buffalo Bayou at Shepherd Drive	40
Figure 4.3	Naturalized Flows at USGS Gage 08074500, White Oak Bayou at Heights Blvd	41
Figure 5.1	Bacteria Sampling Results, November 2002 to September 2003	53
Figure 5.2	Locations of WWTPs and Sampling Sites for WWTP Effects on Stream Sediments	55
Figure 5.3	Total Solids and Volatile Solids Data for Studying Wwtp Effects on Stream Sediments	59
Figure 5.4	Moisture Content and Ec Data for Studying Wwtp Effects on Stream Sediments	60
Figure 5.5	Locations of Sampling Sites for Settling Tests	63
Figure 5.6	TSS Settling Test Results	66

Figure 5.7 EC Settling Test Result 68

Figure 6.1 Reservoir Sampling Locations 73

Figure 6.2 Reservoir Discharge 75

Figure 6.3 Reservoir Storage 75

Figure 6.4 Rainfall Distribution for Wet Weather Event 1 83

Figure 6.5 EC Concentrations for Wet Weather Event 1 86

Figure 6.6 Phosphorous Concentrations for Wet Weather Event 1 87

Figure 6.7 TSS Concentrations for Wet Weather Event 1 88

Figure 6.8 Rainfall Distribution for Wet Weather Event 2 90

Figure 6.9 EC Concentrations for Wet Weather Event 2 94

Figure 6.10 TSS Concentrations for Wet Weather Event 2 95

Figure 6.11 Phosphorous Concentrations for Wet Weather Event 2 96

Figure 6.12 Rainfall Distribution for Wet Weather Event 3 98

Figure 6.13 EC Concentrations for Wet Weather Event 3 102

Figure 6.14 TSS Concentrations for Wet Weather Event 3 103

Figure 6.15 Phosphorous Concentrations for Wet Weather Event 3 104

Figure 6.16 Reservoir Dynamics During June and July 2004 111

Figure 6.17 Results of Targeted Reservoir Sampling for EC 117

Figure 6.18 Results of Targeted Reservoir Sampling for TSS 118

Figure 6.19 Results of Targeted Reservoir Sampling for TDS 119

Figure 7.1 Sanitary Manholes in BB & WOB Watersheds with SSO Excursion Records . 124

Figure 7.2 Example Buffer Zones and SSO Manhole Locations 131

Figure 8.1 Locations of Sampled WWTP Outfalls 148

Figure 8.2 Results of WWTP Outfall Sampling 153

Figure 9.1 *E. coli* Isolation Procedure 160

Figure 10.1.1 Daily Flows at City of Houston Plants 188

Figure 10.1.2 QQ-normal plots of non-transformed flow data 191

Figure 10.1.3 QQ-normal plots of log-transformed WWTP flow data 192

Figure 10.1.4 Hourly Flow at Northwest WWTP over a 1-Week Period 195

Figure 10.1.5 Comparison of Actual and Predicted TVF Daily Averages for Six City of Houston Plants 198

Figure 10.2.1 Precipitation Data for 2001 through 2003 203

Figure 10.2.2 Location of Rain Gauges in Buffalo and Whiteoak Bayou Watersheds 204

Figure 10.2.3 Potential Evapotranspiration Data for 2001 to 2003 204

Figure 10.2.4 Evaporation Data for 2001 to 2003 206

Figure 10.2.5 Barker and Addicks Reservoir Flows 208

Figure 10.2.6 Buffalo Bayou Flows for 2001-2003 209

Figure 10.2.7 Whiteoak Bayou Flows for 2001-2003 210

Figure 10.2.8 Observed EC data from 2001 to 2003 211

Figure 10.3.1 TSARP Subwatershed Delineation and Stream System 214

Figure 10.3.2 TSARP DEM Data 215

Figure 10.3.3 H-GAC Land Use/Land Cover Data 217

Figure 10.3.4 Locations of Wastewater Treatment Plants within Study Subwatersheds 218

Figure 10.3.5 Example TSARP HEC-RAS Model Showing Geo-Referenced Cross

Sections 224

Figure 10.3.6 Comparison of Observed and Modeled Reservoir Discharges 232

Figure 10.3.7 Observed and Modeled Time Series 233

Figure 10.3.8 Comparison of Observed to Modeled Flow Duration Curves for Buffalo Bayou 235

Figure 10.3.9 Comparison of Modeled and Observed Flow in Buffalo Bayou 237

Figure 10.3.10 Modeled and Observed EC Concentrations for Buffalo Bayou 243

Figure 10.4.1 Observed and Modeled Time Series 248

Figure 10.4.2 Comparison of Observed to Modeled Flow Duration Curves for Whiteoak Bayou 250

Figure 10.4.3 Modeled versus Observed Flow in Whiteoak Bayou 252

Figure 10.4.4 Modeled and Observed EC Concentrations for Whiteoak Bayou 254

CHAPTER 1

INTRODUCTION

Buffalo Bayou (Segment 1013 and 1014) and Whiteoak Bayou (Segment 1017) are considered impaired water bodies for contact recreation, as they do not meet pathogen water quality standards. As a result, these two bayous were placed on the Texas' Clean Water Act §303(d) List in 1996 and this study was initiated in 2001. The purpose of this study is to provide the TCEQ with the information and assistance necessary for the preparation of a Total Maximum Daily Load (TMDL) for the pathogen impairments in Buffalo and Whiteoak Bayous.

There have been several work orders comprising this study since the initiation of the project. During fiscal year 2001, Work Order 1 was completed to provide analysis of historical information for current levels and trends and as well as an assessment of the major sources of bacteria to the two bayous. The work order demonstrated the regularity and magnitude of bacteria exceedances and evaluated the trends in the FC historical data. Work Order 2 was completed in fiscal year 2002, with an investigation of suspected sources of bacteria, including sediment, wastewater treatment plants, and dry weather storm sewer flows. The development of a water quality model was also undertaken during Work Order 2. Work Order 5 was completed in fiscal year 2003, with refinements to the model undertaken as well as investigation of current issues such as bacteria in sediment, potential load allocation issues and best management practices that may be practical for application in the study watersheds. The most recent work order, Work Order 6, was completed during fiscal year 2004 (September 1, 2003 to August 31, 2004) and was aimed at identifying additional potential sources of bacteria into the bayous. This final report summarizes findings from Work Order 6.

There are several tasks that were examined in Work Order 6, and its two associated amendments. Table 1.1 describes each of the tasks and lists the chapter in the report detailing progress on each task. In Chapter 2, the efforts undertaken to facilitate stakeholder involvement are described. In Chapter 3, the findings associated with the collection and analysis of biosolids data in the Buffalo and Whiteoak Bayou watersheds are discussed. An analysis of water rights and the potential impacts of the proposed diversions are examined in Chapter 4. Chapter 5 describes efforts undertaken to characterize sediment in runoff as well as bacteria levels associated with particulate matter. In Chapter 6, the results of sampling of the Addicks and Barker Reservoirs under wet and dry weather conditions are reported. Chapter 7 and Chapter 8 present information regarding the impact of WWTPs on the bayous, with Chapter 7 examining overflows and bypasses and Chapter 8 reporting results from in-stream sampling. Chapter 9 presents the results of bacteria source tracking undertaken in the Buffalo and Whiteoak Bayou watersheds, including sampling of both fecal sources as well as water sampling. The results of the expansion of the Buffalo Bayou model to include areas above the reservoir and the inclusion of time-varying wastewater treatment plant flows is presented in Chapter 10. Finally, the development of the Quality Assurance Project Plan (QAPP) and the associated quality control tasks to demonstrate compliance with the QAPP are presented in Chapter 11 of this document.

Table 1.1 Description of Tasks Associated with Work Order 6

Task #	Task Description	Chapter #
2	Participate in stakeholder process;	2
3	Develop a quality assurance project plan (QAPP) for additional data collection;	11
4	Finalize bacteria source tracking (BST) sampling plan;	9
5	Assess the impact of possible biosolid releases on bacteria levels;	3
6	Assess sediment contributions;	5
7	Investigate the levels of bacteria from Addicks and Barker reservoirs;	6
8	Quantify loads of bacterial indicators to the bayous from overflows and bypasses;	7
9	Assess *E. coli* levels downstream of WWTP outfalls;	8
10	Expand the HSPF TMDL model for Buffalo and Whiteoak Bayous to include additional sources evaluated as part of this work order as appropriate;	10
11	Expand the antibiotic resistance profiling (ARP) database;	9
12	Conduct bacteria source tracking (BST) sampling and analyses;	9
13	Expand the HSPF TMDL model for Buffalo Bayou to include areas above Addicks and Barker reservoirs;	10
14	Refine the existing modeling of point sources using time-varying flow and concentrations;	10
15	Review Region H Water Availability Model (WAM) including assumptions and results relating to reuse and diversions in smaller tributaries	4
16	Gather, review, and summarize applications for reuse and diversion of surface waters in the Houston area	4
17	Formulate how possible reductions in WWTP flow, as well as changes in stream diversions and return flows, would operate under different stream flow and seasonal conditions	4
18	Use the refined model to analyze the effects of diversions and withdrawals on attaining water quality criteria under a range of flow conditions and assess the uncertainty in refined model predictions	4
19	Formulate draft limitations on withdrawals and diversions that may be necessary to maintain acceptable levels of indicator bacteria	4
20	Develop Work Plan for FY 2005	12
21	Expand the Houston Bacteria Source Tracking Database	9

CHAPTER 2

STAKEHOLDER/PUBLIC EDUCATION AND INVOLVEMENT

2.1 SUMMARY OF SUPPORT ACTIVITIES

The project team supported the stakeholder process facilitated by the Houston Galveston Area Council (HGAC) and Mary Jane Naquin. The following support tasks were undertaken:

- Development of informational materials summarizing the technical aspects of the project for electronic and hard copy distribution at stakeholder meetings including documents, maps, and quarterly reports;
- Preparation of web based project informational briefs;
- Participation in three stakeholder meetings (October 15, 2003; January 28, 2004 and May 18, 2004);
- Preparation of responses to questions and information requests from stakeholders and providing rationale for whether or not certain requests by stakeholders for refinement in technical analysis can or cannot be achieved;
- Preparation of responses to questions and information requests regarding the unofficial dog park located at Allen Parkway/Montrose; and
- Providing technical expertise on issues related to microbiological, public health, urban wastewater infrastructure and water quality.

2.2 TECHNICAL PRESENTATIONS AT STAKEHOLDER MEETINGS

The slide presentations from the three stakeholder meetings are included in Appendix A.

CHAPTER 3

ASSESSMENT OF BIOSOLIDS RELEASES

Biosolids are the by-product of sewage sludge that has been treated and thus can be beneficially reused. When treated and processed, sewage sludge is considered biosolids which can be safely recycled and applied as fertilizer to improve and maintain productive soils and stimulate plant growth. Releases of sludge or biosolids can occur during high flow events if wastewater treatment facilities are not properly managing solids levels or if the inflows into the plant are extremely large. There are anecdotal reports from local TCEQ field inspectors of deliberate wasting of solids under normal flows, presumably to avoid the cost of biosolids processing and disposal. These biosolids from domestic wastewater treatment could be a significant component of stream sediment bacteria concentrations. To assess the extent of these activities, a reconciliation of reported biosolid volumes and estimated biosolids generation from self-reported effluent data was undertaken. Two methods for determining the amount of biosolids generated by a WWTP were used. The first method is the Biosolids Generating Factor (BGF) method that uses a factor to determine the amount of biosolids produced by a plant based on its flow. The second method involves a mass balance approach that takes into account the various treatment units at each plant. Additionally, wastewater treatment plant (WWTP) records at Region 12 were researched to compile a database of biosolids generation data for comparison with the estimated values using the two methods described above. This section will first discuss the biosolids database from TCEQ records and then provide a detailed explanation of the two biosolids generation methods.

3.1 BIOSOLIDS SELF-REPORTING DATA

The project team developed a database for wastewater treatment plants (WWTPs) in Buffalo Bayou and Whiteoak Bayou. The majority of the data came from the TCEQ database with the exception of the most recent data from 2002 to 2003 that came from the EPA Envirofacts database. There are a total of 146 WWTP plants in the two watersheds, with data on biosolids collected from 86 plants. An information data sheet was developed to summarize the available data that were gathered for each plant. The information sheet includes general information for the plant, flow and sludge data, contact information, design data, and a flow diagram. The developed information sheets are included in Appendix B.

Plants in the watersheds can be divided into two categories: domestic and industrial. Table 3.1 characterizes the 88 plants having biosolids data by type (domestic or industrial), flow, and sludge treatment method. Only 3 plants were classified as industrial out of the 88. It can also be seen that the primary method used for stabilization of sludge is aerobic digestion (60 WWTPs). As shown in Table 3.1, nearly 85% of the plants treat an average daily flow rate of less than 1 million gallons per day (MGD); the remaining 15% of the plants provide approximately 77% of the wastewater treatment capacity for the Buffalo and Whiteoak Bayou watersheds.

The database of 88 WWTPs will be used later in this chapter to compare the estimated biosolids and reported biosolids. Additionally, this database provides the flow data and TSS data needed for calculating estimates of biosolids generated. An important factor in using the database is that paired flow and sludge data were needed to determine how accurate the two methods were in their estimates. Among the 79 WWTPs that had biosolids data from 2002-203, there were only

Table 3.1 Characteristics of Wastewater Treatment in Buffalo and Whiteoak Bayous

Variable	**Category**	**Number of Plants**
Type	Municipal	85
	Industrial	3
Flow	< 1 MGD	74
	1< Flow <10 MGD	14
Treatment Method	aerobic digester	60
	Unknown	28

53 WWTPs which reported both flow and sludge data in the Envirofacts database. These 53 plants were used for the calculations presented in the following sections.

Reported biosolids, compiled from 1994 to 2003 are listed in Table 3.2. The data in Table 3.2 demonstrate that the reported sludge amounts vary greatly between plants as evidenced by the very high standard deviation and sometimes dramatically different sludge production for some plants from year to year. As can be seen in Table 3.2, the reported biosolids in 2002-2003 ranged between 0 and 4,118 dry metric tons/year. It is noted some of the highly variable sludge volumes from year to year may be due to the TCEQ reporting system. The TCEQ reporting system requires that the *disposal* of sludge be reported, and not the generation. Therefore, the reported sludge data may not include all the sludge generated in a single year and depending on when the sludge was hauled away, the total during one year may include sludge generated in the previous year.

The cumulative total (for 79 plants) for 2002-2003 was 7,298 dry metric tons for Buffalo Bayou and 5,905 dry metric tons for Whiteoak Bayou.

3.2 BIOSOLID GENERATION FACTOR METHOD

The US EPA developed a method that uses biosolids generation factors (BGFs) for estimating biosolids production in the United States (US EPA, 1999).

The data used by EPA to develop the BGFs came from four primary sources: the 1988 National Sewage Sludge Survey (NSSS), the Rule Impact Assessment (RIA) for the Biosolids Rule (US EPA, 1993), the 1988 Needs Survey providing data on the mass of biosolids, and the 1988 Needs Survey providing flow data.

Table 3.2 Reported Biosolids

TCEQ ID	Watershed	Average Biosolids (Metric ton/yr)	Reported Biosolids (metric ton/yr)													
			2003[1]	02-03[2]	01-02[3]	00-01[4]	99-00[5]	2001[6]	2000[7]	1999[8]	98-99[9]	1998[10]	1997[11]	1996[12]	1995[13]	1994[14]
10584	BB	377.6		356.3					399.0							
10706	BB	284.5		284.5												
11152	BB	344.6		313.7	375.2					345.1						
11284	BB	67.2		75.9	17.2				108.4							
11290	BB	476.3		365.6		604.7		474.4		460.5						
11472	BB	45.9			45.9											
11486	BB	93.1		118.5	57.7	99.8				96.5						
11523	BB	162.8		162.8												
11598	BB	50.6		50.6												
11682	BB	210.5		210.5												
11836	BB	46.5		52.3	28.2					59.0						
11883	BB	50.9		80.4	28.7					43.6						
11893	BB	269.0		268.2		260.4					278.4					
11906	BB	51.2			53.6	50.8					49.3					
11917	BB	31.0		60.7			17.4				14.8					
11935	BB	35.1		35.1												
11969	BB	189.5		234.8								144.3				
11989	BB	24.8			42.5		7.1									
12110	BB	3.8		3.2						4.4						
12124	BB	38.5		38.5												
12128	BB	83.4		53.6						106.9			89.8			
12140	BB	26.7			26.7											
12189	BB	10.6				10.6										
12209	BB	51.0		51.0												
12222	BB	7.0		7.0												
12223	BB	64.0			64.0											
12233	BB	0.6		0.6												
12247	BB	19.0								11.0		30.1			16.0	
12289	BB	88.1		78.6				49.7				145.3	106.8	60.3		
12298	BB	25.0		11.9	31.1	30.5	26.7									
12304	BB	73.4		73.4												
12346	BB	23.9		22.7	25.1											
12356	BB	23.2		23.2												
12370	BB	14.0		16.9	14.3	10.8										
12427	BB	0.0		0.0												
12447	BB	66.2		66.2												
12466	BB	29.3		0.8	28.2					59.0						
12479	BB	81.3		48.8		125.0					90.9	60.4				
12682	BB	5.2		6.6	3.7											
12685	BB	15.6		15.6												
12726	BB	92.0		150.7		45.6		79.6								
12802	BB	40.7		64.6	16.8											
12830	BB	0.0		0.0												
12834	BB	7.9		7.9												
12841	BB	12.9		16.1					9.7							
12858	BB	0.0		0.0												
12927	BB	0.0		0.0												
12949	BB	24.1		24.1												
13021	BB	72.4		72.4												
13228	BB	12.2		12.2												
13245	BB	4.6		4.6												
13328	BB	7.7		7.7												
13433	BB	9.8		9.8												
13484	BB	1.8		1.8												
13558	BB	120.6		158.9	122.6					80.4						
10495-030	BB	2823.0		2823.0												
10495-109	BB	589.5		589.5												
11792-022	BB	45.4		60.6						47.5			28.1			
11979-022	BB	26.0		25.4	31.0						13.9	15.1	44.5			
13172-022	BB	46.3		80.4		31.7		26.9								
10876	WOB	128.1		128.4	127.8											
11005	WOB	11.4		11.4												
11051	WOB	5.9		6.4												5.3
11153	WOB	296.8		326.0	289.6		247.0			324.6						

TCEQ ID	Watershed	Average Biosolids (Metric ton/yr)	Reported Biosolids (metric ton/yr)													
			2003[1]	02-03[2]	01-02[3]	00-01[4]	99-00[5]	2001[6]	2000[7]	1999[8]	98-99[9]	1998[10]	1997[11]	1996[12]	1995[13]	1994[14]
11188	WOB	38.5		38.5												
11193	WOB	97.0		97.0												
11273	WOB	49.6		49.6												
11485	WOB	73.2		66.8						79.6						
11538	WOB	156.0		152.6			159.4									
11563	WOB	152.9		152.9												
12132	WOB	0.6		0.6												
12139	WOB	6.3		6.3												
12342	WOB	4.3			2.4	6.3										
12443	WOB	1.1		1.1												
12465	WOB	0.2								0.2						
12552	WOB	4.2		2.9	5.5											
12574	WOB	11.0		11.0												
12681	WOB	34.7		40.2	29.2											
12714	WOB	16.9		19.5	26.7	4.4										
12795	WOB	47.1		47.1												
13623	WOB	28.1		28.8									27.3			
13689	WOB	84.9		84.9												
13764	WOB	5.4		5.4												
10495-076	WOB	3027.7		4118.0	3783.0	1182.0										
10495-099	WOB	288.0		288.0												
10495-139	WOB	15.0		15.0												
10876-002	WOB	130.5	136.9	124.1												
12552-002	WOB	3.9		2.5	5.3											
Summary Statistics																
Overall	Min	0.00		0.0	2.4	4.4	7.1	26.9	9.7	0.2	13.9	15.1	27.3			
	Max	3027.7		4118.0	3783.0	1182.0	247.0	474.4	399.0	460.5	278.4	145.3	106.8			
	Average	138.8		166.1	203.1	189.4	91.5	157.7	172.4	122.7	89.5	79.0	59.3			
	Median	36.8		47.1	28.9	45.6	26.7	64.7	108.4	69.3	49.3	60.4	44.5			
	Total	12216.9	136.9	13123.0	5281.9	2462.6	457.6	630.6	517.1	1718.0	447.3	395.1	296.5	60.3	16.0	5.3
	Stdev	441.1		556.6	735.3	341.1	106.8	212.2	202.4	144.2	110.2	62.2	36.8			
	Count	88	1	79	26	13	5	4	3	14	5	5	5	1	1	1
BB	Min	0.0		0.0	3.7	10.6	7.1	26.9	9.7	4.4	13.9	15.1	28.1			
	Max	2823.0		2823.0	375.2	604.7	26.7	474.4	399.0	460.5	278.4	145.3	106.8			
	Average	125.0		137.7	56.3	127.0	17.1	157.7	172.4	119.4	89.5	79.0	67.3			
	Median	39.6		50.6	29.8	48.2	17.4	64.7	108.4	59.0	49.3	60.4	67.2			
	Total	7497.9		7298.1	1012.5	1269.9	51.2	630.6	517.1	1313.6	447.3	395.1	269.2	60.3	16.0	
	Stdev	373.6		394.3	83.9	184.0	9.8	212.2	202.4	145.8	110.2	62.2	37.1			
	Count	60	0	53	18	10	3	4	3	11	5	5	4	1	1	0
WOB	Min	0.2		0.6	2.4	4.4	159.4			0.2						
	Max	3027.7		4118.0	3783.0	1182.0	247.0			324.6						
	Average	164.3		218.7	533.7	306.1	203.2			134.8						
	Median	34.7		40.2	27.9	19.0	203.2			79.6						
	Total	4765.3	136.9	5905.3	4269.4	1224.4	406.4			404.4			27.3			5.3
	Stdev	556.4		783.8	1316.6	584.1	61.9			169.1						
	Count	28	1	26	8	3	2	0	0	3	0	0	1	0	0	1

10706

Source of Data: TCEQ records and EPA Envirofacts database

[1] 2003 (from Jan. 1 2003 to Dec. 31 2002)

[2] 02-03 (from Aug. 1 2002 to July 31 2003)

[3] 01-02 (from Aug. 1 2001 to July 31 2002)

[4] 00-01 (from Aug. 1 2000 to July 31 2001)

[5] 99-00 (from Aug. 1 1999 to July 31 2000)

[6] 2001 (from Jan. 1 2001 to Dec. 31 2001)

[7] 2000 (from Jan. 1 2000 to Dec. 31 2000)

[8] 1999 (from Jan. 1 1999 to Dec. 31 1999)

[9] 98-99 (from Aug. 1 1998 to July 31 1999)

[10] 1998 (from Jan. 1 1998 to Dec. 31 1998)

[11] 1997 (from Jan. 1 1997 to Dec. 31 1997)

[12] 1996 (from Jan. 1 1996 to Dec. 31 1996)

[13] 1995 (from Jan. 1 1995 to Dec. 31 1995)

[14] 1994 (from Jan. 1 1994 to Dec. 31 1994)

The 1988 NSSS (as reported in US EPA, 1993) was conducted to support the development of the 503 Biosolids Rule and was conducted on 479 publicly owned treatment works (out of an estimated total of 11,400 that year). The survey participants were asked to provide data on the annual sludge and biosolids generation on a dry weight basis. Three Houston plants were included in this survey, the Sims WWTP, the Parkglen WWTP and the Southwest WWTP. The NSSS only included publically owned treatment works (POTWs) practicing secondary treatment (biological treatment to reduce biological oxygen demand), not primary treatment (simple gravity separation and screening of wastewater); additionally it did not provide information on federal and private facilities.

The 1988 Needs Survey provided the flow data for EPA's BGF calculation. The 1988 Needs Survey was intended to provide the US EPA with detailed information as to the costs and needs for POTWs to comply with the Clean Water Act. A total of 24,153 wastewater treatment facilities were included in the 1988 Needs Survey (US EPA, 1989). The flows were reported as the annual average daily total flow and the annual average daily design flow in the survey.

Biosolids generation factors were calculated using the amount of biosolids generated in the US in 1988 and the total design flow for all primary and secondary WWTPs. Data on biosolids generation for the primary plants were provided by the RIA for Part 503. The BGFs were calculated by dividing the total dry mass of biosolids generated in 1988 in dry tons by the annual average daily flow in MGD. BGFs were developed for secondary treatment as shown in equations 3.1 and 3.2 below.

$$BGF_{primary} = \frac{\textit{Biosolids Generated in 1988 Primary Processes (U.S.drytons)}}{\textit{Total 1988 Annual Primary Wastewater Flow (MGD)}} \quad \text{(Eqn 3-1)}$$

$$BGF_{secondary} = \frac{Biosolids\ Generated\ in\ 1988\ Secondary\ Processes\ (U.S.drytons)}{Total\ 1988\ Annual\ Secondary\ Wastewater\ Flow\ (MGD)} \quad \text{(Eqn 3-2)}$$

The $BGF_{primary}$ was calculated to be 203 dry tons/MGD and the $BGF_{secondary}$ was calculated to be 206 dry tons/MGD using the above equations. It should be noted that the units of the BGF do not imply that the biosolid generation is calculated on a daily basis. Although the daily flow is used to derive the BGFs, the biosolids value that results when using the BGF is the mass of biosolids generated per year (in dry tons). This is because of the data that were used to develop the BGF: the annual average daily flow and the yearly biosolids generated. Using self-reported flows, the BGFs can be used to provide a rough estimate of the generated biosolids for a plant per year.

The US EPA BGFs (US EPA, 1999) were used to develop estimates of the amount of biosolids generated by WWTPs in Buffalo and Whiteoak Bayou. Based on the data gathered in this project, it was determined that all wastewater facilities in the two watersheds use secondary treatment processes. The average flow data for each plant were determined primarily by querying the EPA Envirofacts database, but supplementary data were obtained from the TCEQ self-reporting database (TRACS) and the database developed from the TCEQ Region 12 files. The resulting flow was then multiplied by the $BGF_{secondary}$ of 206 dry tons/MGD to yield an estimate of biosolids produced per year for each plant. The results are shown in Table 3.3. As can be seen in Table 3.3, the calculated values totaled 6,409 dry metric tons for the 53 plants that had data in 2002-2003. The reported biosolids total was 8,528 dry metric tons, 33% more than the calculated value. When plant 10495-076 is removed from the calculations, the reported and estimated totals are much closer, within 3% of each other.

Table 3.3 Reported and Estimated Biosolids Using EPA's BGF Method

TCEQ ID	Watershed	Flow[1] MGD	Estimated Biosolids[2] Using BGF (dry metric ton/yr)	Biosolids Reported[3] (metric ton/yr)
10584	BB	2.139	399.8	356.3
10706	BB	1.082	202.2	284.5
11284	BB	0.606	113.3	75.9
11290	BB	2.618	489.2	365.6
11486	BB	0.582	108.8	118.5
11598	BB	0.691	129.2	50.6
11682	BB	0.362	67.7	210.5
11836	BB	0.294	54.9	52.3
11883	BB	0.485	90.6	80.4
11893	BB	1.285	240.0	268.2
11969	BB	0.620	115.8	234.8
12124	BB	0.307	57.3	38.5
12128	BB	0.496	92.6	53.6
12222	BB	0.052	9.7	7.0
12233	BB	0.001	0.1	0.6
12289	BB	0.470	87.9	78.6
12298	BB	0.114	21.3	11.9
12304	BB	0.407	76.1	73.4
12356	BB	0.015	2.9	20.3
12427	BB	0.000	0.0	0.0
12447	BB	0.307	57.5	66.2
12682	BB	0.059	11.1	6.6
12685	BB	0.107	20.0	15.6
12726	BB	0.320	59.8	150.7
12830	BB	0.004	0.7	0.0
12841	BB	0.059	10.9	16.1
12858	BB	0.016	2.9	0.0
13228	BB	0.064	12.0	12.2
13245	BB	0.225	42.0	4.6
13433	BB	0.026	4.8	9.8
13484	BB	0.060	11.1	1.8
10495-109	BB	4.347	812.4	575.0
11792-022	BB	0.293	54.7	60.6
13172-022	BB	0.370	69.1	80.4
11005	WOB	0.182	34.0	11.4
11051	WOB	0.034	6.3	6.4
11153	WOB	1.436	268.4	326.4
11188	WOB	0.264	49.4	38.5
11193	WOB	0.410	76.6	97.0
11273	WOB	0.455	85.0	49.6
11538	WOB	0.967	180.7	152.6

TCEQ ID	Watershed	Flow[1] MGD	Estimated Biosolids[2] Using BGF (dry metric ton/yr)	Biosolids Reported[3] (metric ton/yr)
11563	WOB	0.739	138.1	152.9
12132	WOB	0.040	7.4	0.6
12139	WOB	0.020	3.7	6.3
12443	WOB	0.002	0.3	1.1
12552	WOB	0.007	1.3	2.9
12681	WOB	0.174	32.5	0.0
12714	WOB	0.137	25.6	19.5
12795	WOB	0.254	47.4	47.1
13623	WOB	0.050	9.3	28.8
13689	WOB	0.376	70.3	84.9
10495-076	WOB	9.868	1844.1	4118.0
12552-002	WOB	0.004	0.8	2.5
	Total	34.298	6409.6	8527.6
	Count	53		

Notes:
1 Total annual flow (MGD) from 2002 to 2003
2 Biosolids generating factor from EPA report
3 Biosolids reported data from 2002 from 2003

Since the EPA method was based on national data, another method for estimating sludge volumes was selected that relies on local WWTP-specific data. This method, referred to the solids mass balance method, is described in the next section.

3.3 SOLIDS MASS BALANCE METHOD

Sludge is generated in the primary settling tanks and the activated sludge system. In most cases, primary sedimentation tanks are used to remove readily settleable solids and floating material, thereby reducing the suspended solids content. Properly designed sedimentation tanks typically remove 50 to 70 percent of the suspended solids and 25 to 40 percent of the influent BOD_5. However, most of the plants in Buffalo and Whiteoak Bayous are relatively small, with 82% having flows less than 1 MGD (Table 3.1). Therefore, the treatment units that generate sludge include aeration, secondary clarification, and aerobic digestion. The solids mass balance approach involves estimating sludge production based on the treatment units used at a given plant.

Figure 3.1 shows a generalized schematic diagram of a typical WWTP in Buffalo and Whiteoak Bayous. The schematic illustrates the process units where solids are removed, including the bar screen, the aeration tank and the secondary clarifier (the two together are considered as one biological process), and the digester (stabilized sludge). One of the WWTPs (permit number 12298) is used to illustrate the mass balance estimation method.

The assumptions employed for this plant were applied to all plants that have data during the same time period (2002-2003). The design capacity of the plant is 0.9 MGD, but average flow from August 2002 to July 2003 was 0.114 MGD (Table 3.2). Influent wastewater is primarily characterized by its biochemical oxygen demand (BOD_5) and total suspended solids (TSS). These

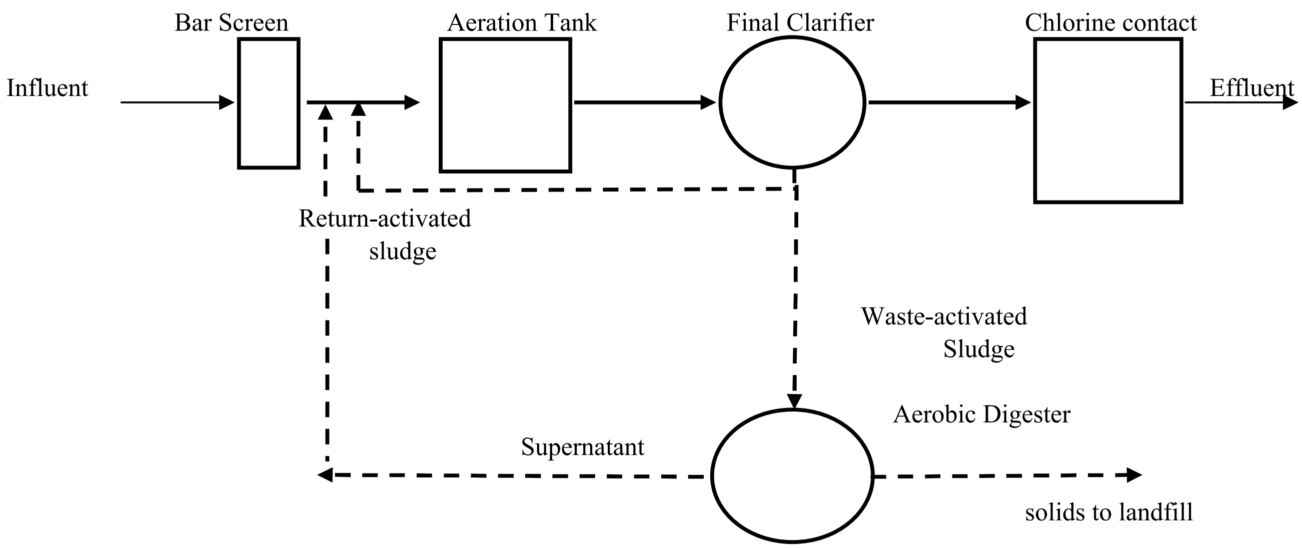


Figure 3.1 Generalized Schematic of a Typical WWTP in Buffalo and Whiteoak Bayou

variables average 190 mg/L and 210 mg/L, respectively, in a typical WWTP (Metcalf and Eddy, 2002). In the absence of influent data from WWTPs in the watersheds these typical values are used in the simplified mass balance. The effluent permit limits for BOD_5 and TSS are in general a daily average of 10 mg/L and 15 mg/L, respectively. The average BOD_5 and TSS data for plant 12298 effluent are reported to be 4.4 mg/L and 2.5 mg/L from 2000 to 2003 based on the US EPA Envirofacts database.

3.3.1 WASTE ACTIVATED SLUDGE (WAS)

The determination of WAS production in the secondary clarifier requires that the aeration tank, secondary clarifier and return activated sludge rate be treated as one single biological process. The activated sludge process is used to remove the carbonaceous organic matter (defined by BOD_5). The amount of volatile suspended solids (VSS) for carbonaceous, nitrogenous, and nonbiodegradable volatile suspended solids is calculated using equation below.

$$P_x = P_{xc} + P_{xn} + P_{xi} \qquad \text{(Eqn 3-3)}$$

Where:

P_x = VSS total sludge production
P_{xc} = VSS carbonaceous sludge production
P_{xn} = VSS nitrogenous sludge production
P_{xi} = VSS inorganic solids

The carbonaceous sludge production or P_{xc} accounts for the heterotrophic biomass growth, cell debris from endogenous decay, and nonbiodegradable VSS in the influent wastewater is calculated:

$$P_{xc} = Y_{c,obs} * Q * (S_0 - S_e) * \frac{1kg}{10^3 g} \qquad \text{(Eqn 3-4)}$$

Where:

$Y_{c,obs}$= observed yield coefficient, 1 g VSS/g BOD
Q = system flow rate, MGD
S_0 is the influent CBOD concentration, 190 mg/L
S_e is the effluent CBOD concentration, reported value from each plant
CBOD is the carbonaceous biochemical oxygen demand

The observed yield coefficient is based on the amount of solids production measured relative to the substrate (BOD) removal, and calculated in terms of mg VSS/mg BOD or mg TSS/mg BOD. The observed yield coefficient includes heterotrophic biomass, cell debris, and nonbiodegradable VSS in the influent. The impact of nonbiodegradable influent VSS on the observed yield depends on the wastewater characteristics and the type of pretreatment. The observed yield coefficient would ideally be calculated for each facility using temperature and the solids retention time (SRT) in conjunction with Figure 3.2.

However, site-specific data such as temperature, SRT, influent BOD, and influent TSS were not found in the TCEQ and EPA records. Therefore, the observed yield coefficient for a plant without primary treatment can range from 0.7 mg to 1 mg VSS/mg BOD. For a small plant, the SRT is generally less than 1 day. For the simplified mass balance, the SRT was assumed to be one day which would translate to a 1 mg VSS/mg BOD for the carbonaceous yield coefficient.

The value of (S_0-S_e) in equation 3-4 is determined as the difference between influent and effluent BOD. Typical values of influent BOD are around 190 mg/L (Metcalf and Eddy, 2002), while effluent BOD concentrations are obtained from the EnviroFacts database for each plant. Using the equations described above, a total of 29.54 Met ton/yr (80.92 kg/d) VSS carbonaceous sludge

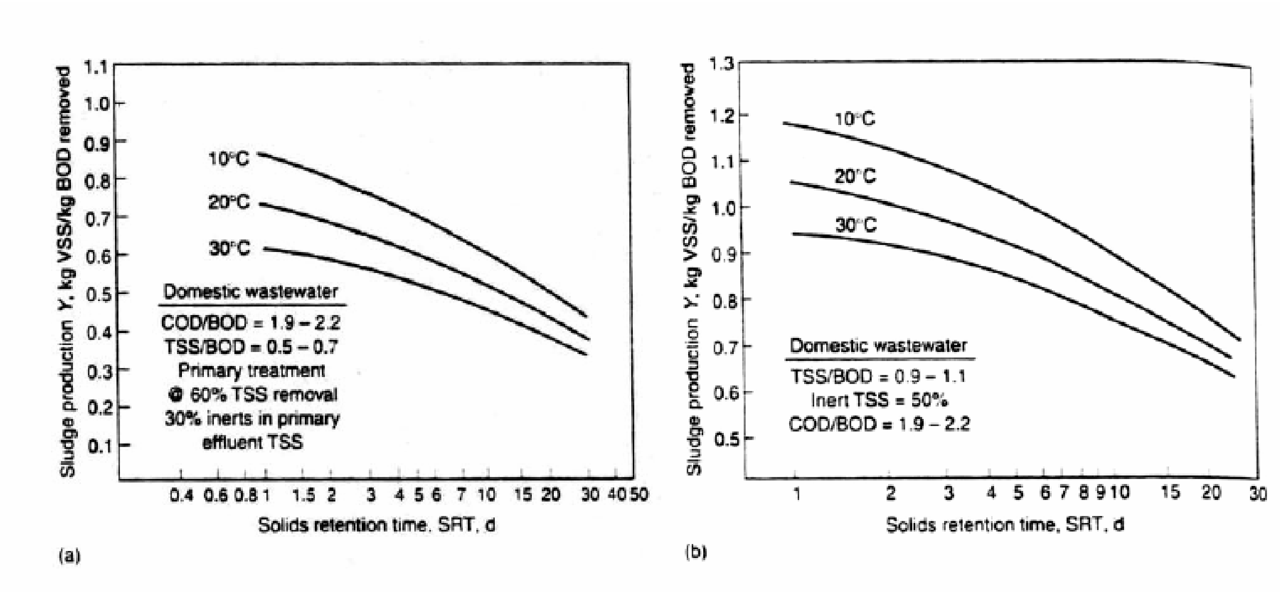


Figure 3.2 Relationship between Solids Retention Time (SRT) and Yield Coefficient (Y)
(adapted from Metcalf and Eddy, 2002)

was estimated to be produced by the biological processes at the Fort Bend County Mud 34 WWTP (Permit # 12298).

Nitrogenous sludge production or $P_{x,n}$ is calculated as shown in Equation 3-5 below. Without site-specific data, the nitrogenous yield coefficient for plants was estimated to be 0.12 g VSS/g NH4-N from activated sludge nitrification kinetic coefficients at 20°C (Metcalf and Eddy, 2002). The influent and effluent nitrogen concentration were also assumed to have typical values on the order of 25mg/L and 3mg/L, respectively (Metcalf and Eddy, 2002).

$$P_{xn} = Y_{n,obs} * Q * (N_0 - N_e) \qquad \text{(Eqn 3-5)}$$

Where:

Q = system flow rate, MGD
$Y_{n,obs}$ = observed yield coefficient, 0.12d-1
N_o = influent nitrogen concentration, 25 mg/L
N_e = effluent nitrogen concentration, 3 mg/L

Therefore, 0.416 met ton/yr (1.14 kg/day) of VSS nitrogenous sludge was estimated to be generated from the plant (permit number 12298).

Inorganic solids in the influent water, influent TSS, and influent VSS contribute to inorganic solids or $P_{x,i}$.

$$P_{xi} = Q * (TSS_0 - VSS_0) \qquad \text{(Eqn 3-6)}$$

Where:

Q = system flow rate, MGD
$P_{x,i}$ = inorganic solids in the influent wastewater
TSS_0 = influent TSS, mg/L
VSS_0 = influent VSS, mg/L

The VSS fraction of the total biomass of carbonaceous and nitrogenous sludge production is approximately 0.85. Thus, Equation 3-3 is modified as follows to calculate the solids production in terms of TSS:

$$P_t = \frac{P_{xc}}{0.85} + \frac{P_{xn}}{0.85} + P_{xi} \qquad \text{(Eqn 3-7)}$$

Where:

P_t = total sludge production
$P_{xc}/0.85$ = carbonaceous sludge production
$P_{xn}/0.85$ = nitrogenous sludge production
P_{xi} = inorganic solids

Thus the carbonaceous sludge production is 34.75 metric ton/yr (95.19 kg/d), nitrogenous sludge production is 0.49 metric ton/yr (1.34 kg/d), and inorganic solids production is 4.96 metric ton/yr (13.59 kg/d).

3.3.2 THICKENING

Thickening is defined as the removal of water from sludge, so that it can be handled in downstream processes, such as digestion, dewatering, drying, and incineration. The five major thickening processes found at municipal wastewater treatment facilities include: gravity thickening, flotation thickening, centrifugal thickening, gravity belt thickening, and Rotary-drum thickening. Most of plants in Buffalo and Whiteoak Bayou watershed do not have a thickening process. There are only 7 plants which use the thickening process (12802, 11670, 11284, 11682, 10584, 11152, 13172-002, 12222). Only one plant (permit number 12802) specified gravity thickening as the type of thickening used in the plant. Because the scale of plants in Buffalo and Whiteoak Bayou is relatively small, the thickening process in this case would be considered inefficient and not cost ineffective.

3.3.3 AEROBIC DIGESTERS

Digestion is a method of sludge stabilization that significantly reduces the amount of solids in sludge. Digestion can be anaerobic or aerobic. Aerobic digestion may be used to treat waste-activated sludge only, mixtures of waste-activated sludge or trickling-filter sludge and primary sludge, or waste sludge from extended aeration plants. Traditionally, aerobic digestion has been used primarily in plants that have flows less than 5 MGD (Metcalf & Eddy, 2002). Only one plant has flow greater than 5 MGD in Buffalo and Whiteoak Bayous (10495-030) while 55% of plants (or 69 plants) have aerobic digesters included in their process schematic.

The reduction of solids mass in an aerobic digester is assumed to take place only with the biodegradable content of the sludge, although there may be some destruction of the nonorganics as well. Volatile solids reductions ranging from 35 to 50 percent are achievable by aerobic digestion (Metcalf and Eddy, 2002). To calculate the amount of biosolids, 42% solids reduction was assumed and applied to all the WWTPs in the two watersheds.

3.3.4 DEWATERING AND BELT PRESSING

Dewatering and belt pressing are biosolids treatment processes. Sludge dewatering involves removal of water to reduce the sludge volume and to meet the target solid concentration for subsequent treatment and disposal. Operators of small WWTPs are faced with a unique problem of sludge dewatering and disposal; the small plants generate too little sludge to effectively use the innovative or sophisticated reuse or treatment technologies, but enough sludge to make it difficult to meet technical and economical requirements. Because most of the WWTPs in the two bayous are permitted for less than 10 MGD, dewatering was not considered.

In belt presses, treated sludge is first introduced on a gravity drainage section where it is allowed to thicken. Only two wastewater treatment plants in both Buffalo and Whiteoak Bayou (11682, 11153) have belt press processes specified in their permit files at TCEQ, thus this process was also not considered.

3.3.5 TOTAL SLUDGE GENERATION

The total sludge amount generated by a plant is the WAS generated minus the return TSS minus the digested sludge. At plant 12298, this would amount to 24.86 metric ton/yr (68.1 kg/d): 34.75 metric ton/yr (95.19 kg/d) carbonaceous sludge production + 0.49 metric ton/yr (1.12kg/d) nitrogenous sludge production + 4.96 metric ton/yr (13.59 kg/d) inorganic solids – 4.02 metric ton/yr (11.01 kg/d) return activated sludge – 11.32 metric ton/yr (31.02 kg/d) digested reduction = 24.86 metric ton/yr (68.1 kg/d). This estimate is the total sludge generated prior to any biosolids processing.

Based on the self-reporting data from the facility, a total of 11.9 dry metric tons of biosolids were disposed of from 2002 to 2003. The reported value is one-half the estimated value. Sludge data gathered for the plant from TCEQ files for prior years, however, show a large amount of sludge in prior years: 31.1 dry metric ton/year from 2002 to 2001, 30.5 dry metric ton/year from 2000 to 2001, and 26.65 dry metric ton/year from 1999 to 2000.

The solids mass balance approach detailed above for plant 12298 was then applied to the remaining plants in the Buffalo and Whiteoak Bayou watersheds. The resulting biosolids estimates are presented in Table 3.4. It should be noted that all values presented in Table 3.4 were calculated using typical values because most of plants do not have specific influent BOD data and detailed information on plant sizing and processes. In general, the reported biosolids were fairly close to the calculated value. The estimated sludge generation at some plants was significantly higher than the reported value (e.g. 12574 and 13245). The reverse is true as well for some plants (e.g. 12949 and 12841). It can also be seen from Table 3.4 that the total calculated value for both watersheds using the solids mass balance approach is about 44% higher than the reported values from the plants.

The data in Table 3.5 include the biosolids generation mass estimated by the BGF and mass balance methods for the 53 plants with paired flow and reported data. The two methods provide comparable results, with 74% of the estimates being within 20% or less of each other. The total sludge generating estimated using the BGF is within 5% of the total calculated using the mass balance method.

A summary of the mass balance calculation for all 53 plants with paired flow and reported biosolids information is presented in Appendix C.

3.3.6 UNCERTAINTY IN SLUDGE ESTIMATION USING MASS BALANCE APPROACH

As discussed in the previous section, the amount of generated sludge in the mass balance approach is calculated using assumptions such as the yield coefficient, influent BOD, influent Nitrogen concentration, effluent Nitrogen concentration, and the ratio VSS of TSS. The calculation,

Table 3.4 Estimated Biosolids by Mass Balance Method (with Min and Max) and Compared to Reported Biosolids

TCEQ ID	Watershed	Flow[1] (MGD)	Estimated Biosolids[2] Using Mass Balance (metric ton/yr)	Minimum[3] Estimated Biosolids (metric ton/yr)	Maximum[4] Estimated Biosolids (metric ton/yr)	Reported Biosolids[3] (metric ton/yr)
10584	BB	2.139	462.2	131.856	853.347	356.3
10706	BB	1.082	235.0	65.616	438.510	284.5
11284	BB	0.606	132.0	35.803	251.234	75.9
11290	BB	2.618	567.7	154.034	1084.913	365.6
11486	BB	0.582	126.7	34.700	239.579	118.5
11598	BB	0.691	150.4	42.370	278.206	50.6
11682	BB	0.362	78.8	17.932	168.201	210.5
11836	BB	0.294	63.7	17.707	119.647	52.3
11883	BB	0.485	105.5	29.322	197.290	80.4
11893	BB	1.285	279.0	78.893	515.534	268.2
11969	BB	0.620	134.9	37.597	251.488	234.8
12124	BB	0.307	66.4	17.864	127.815	38.5
12128	BB	0.496	108.0	30.268	200.231	53.6
12222	BB	0.052	11.3	2.808	22.935	7.0
12233	BB	0.001	0.1	0.040	0.261	0.6
12289	BB	0.470	102.5	28.055	193.586	78.6
12298	BB	0.114	24.9	5.513	53.748	11.9
12304	BB	0.407	88.6	22.042	179.169	73.4
12356	BB	0.015	3.3	0.178	10.151	20.3
12427	BB	0.000	0.0	0.003	0.020	0.0
12447	BB	0.307	66.8	9.504	172.542	66.2
12682	BB	0.059	12.9	1.301	36.201	6.6
12685	BB	0.107	23.2	4.478	53.930	15.6
12726	BB	0.320	69.4	18.168	136.106	150.7
12830	BB	0.004	0.8	0.074	2.239	0.0
12841	BB	0.059	12.8	2.474	29.467	16.1
12858	BB	0.016	3.4	0.194	10.311	0.0
13228	BB	0.064	13.9	2.427	33.647	12.2
13245	BB	0.225	49.0	2.659	148.994	4.6
13433	BB	0.026	5.6	1.588	10.242	9.8
13484	BB	0.060	13.0	2.488	30.101	1.8
10495-109	BB	4.347	946.3	268.754	1737.876	575.0
11792-022	BB	0.293	63.6	12.113	148.182	60.6
13172-022	BB	0.370	80.3	18.984	167.917	80.4
11005	WOB	0.182	39.4	10.022	78.835	11.4
11051	WOB	0.034	7.3	1.399	18.736	6.4
11153	WOB	1.436	312.3	87.587	580.244	326.4
11188	WOB	0.264	57.4	15.964	107.480	38.5
11193	WOB	0.410	87.7	23.274	172.744	97.0
11273	WOB	0.455	99.1	26.586	189.983	49.6
11538	WOB	0.967	210.6	56.909	405.219	152.6
11563	WOB	0.739	161.1	40.268	324.020	152.9
12132	WOB	0.040	8.6	2.351	16.431	0.6
12139	WOB	0.020	4.3	1.212	7.819	6.3
12443	WOB	0.002	0.4	0.109	0.703	1.1
12552	WOB	0.007	1.6	0.408	3.026	2.9

TCEQ ID	Watershed	Flow[1] (MGD)	Estimated Biosolids[2] Using Mass Balance (metric ton/yr)	Minimum[3] Estimated Biosolids (metric ton/yr)	Maximum[4] Estimated Biosolids (metric ton/yr)	Reported Biosolids[3] (metric ton/yr)
12681	WOB	0.174	37.7	9.718	74.818	40.2
12714	WOB	0.137	29.8	8.084	56.603	19.5
12795	WOB	0.254	55.1	11.314	124.314	47.1
13623	WOB	0.050	10.8	1.589	27.483	28.8
13689	WOB	0.376	81.6	20.769	162.984	84.9
10495-076	WOB	9.868	2150.1	520.483	4418.073	4118.0
12552-002	WOB	0.004	0.9	0.003	3.137	2.5
Summary Statistics						
	Average	0.65	140.72	36.53	276.91	161.66
	Median	0.29	63.56	12.11	127.82	47.06
	Total	34.30	7457.95	1935.86	14676.27	8567.81
	Count	53	53	53	53	53

Note

1 Average Flow data from 2002 to 2003
2 Estimated Biosolids by mass balance
Using Average flow, $Y_{c,obs}$=1, Influent BOD=190 mg/L; Influent TSS=210mg/L, $Y_{n,obs}$=0.12, VSS/TSS=0.85
3 Minimum Estimated Biosolids by mass balance
Using Mini flow, $Y_{c,obs}$=0.7, Influent BOD=100 mg/L; Influent TSS=100mg/L, $Y_{n,obs}$=0.1, VSS/TSS=0.9
4 Maximum Estimated Biosolids by mass balance
Using Max flow, $Y_{c,obs}$=1.05, Influent BOD=300 mg/L; Influent TSS=300mg/L, $Y_{n,obs}$=0.15, VSS/TSS=0.8

all values are assumed based on the typical operating conditions. However, and, in order of account for variability in the assumed parameters during operation of the WWTPs, the minimum and maximum sludge generation values are calculated. To estimate minimum biosolids generation, minimum flow, yield coefficient, BOD and TSS values are used. To calculate maximum biosolids generated, maximum flow, yield coefficient, BOD, and TSS are considered. As shown in Table 3.4, the minimum and maximum generated sludge values cover a very wide range of values. This demonstrates that the mass balance approach involves relatively high uncertainty. The total sludge reported by the WWTPs is within the minimum and maximum range of the estimated biosolids generation amounts.

3.4 COMPARISON OF ESTIMATED AND REPORTED BIOSOLIDS

To visualize the difference between the estimated biosolids calculated using the mass balance method and reported data, a linear correlation was developed as shown in Figures 3.3 and 3.4. The estimated biosolids generation data were log transformed (using a log (biosolids + 1) relationship to remove the effects of any zero values on the data set) and to obtain a distribution closer to the normal distribution. Additionally, the data for different flow ranges appeared to behave differently. This differentiation has a basis in the engineering of the plants, as plants with flow greater than 1 MGD are required to meet different regulations (and thus are operated differently) than those with flows less than 1 MGD. Therefore, the data sets were analyzed using two groups: (1) flows less than 1 MGD and (2) flows greater than 1 MGD.

The data in Figures 3.3 and 3.4 demonstrate that a strong, positive correlation between the two exists (R^2=0.89). Given the uncertainty associated with the estimated biosolids using the mass

Table 3.5 Estimated Biosolids by Mass Balance Method and by BGF Method

TCEQ ID	Watershed	Flow[1] MGD	Estimated Biosolids[2] Using Mass Balance (dry metric ton/yr)	Estimated Biosolids[3] Using BGF (dry metric ton/yr)
10584	BB	2.139	462.2	399.8
10706	BB	1.082	235.0	202.2
11284	BB	0.606	132.0	113.3
11290	BB	2.618	567.7	489.2
11486	BB	0.582	126.7	108.8
11598	BB	0.691	150.4	129.2
11682	BB	0.362	78.8	67.7
11836	BB	0.294	63.7	54.9
11883	BB	0.485	105.5	90.6
11893	BB	1.285	279.0	240.0
11969	BB	0.620	134.9	115.8
12124	BB	0.307	66.4	57.3
12128	BB	0.496	108.0	92.6
12222	BB	0.052	11.3	9.7
12233	BB	0.001	0.1	0.1
12289	BB	0.470	102.5	87.9
12298	BB	0.114	24.9	21.3
12304	BB	0.407	88.6	76.1
12356	BB	0.015	3.3	2.9
12427	BB	0.000	0.0	0.0
12447	BB	0.307	66.8	57.5
12682	BB	0.059	12.9	11.1
12685	BB	0.107	23.2	20.0
12726	BB	0.320	69.4	59.8
12830	BB	0.004	0.8	0.7
12841	BB	0.059	12.8	10.9
12858	BB	0.016	3.4	2.9
13228	BB	0.064	13.9	12.0
13245	BB	0.225	49.0	42.0
13433	BB	0.026	5.6	4.8
13484	BB	0.060	13.0	11.1
10495-109	BB	4.347	946.3	812.4
11792-022	BB	0.293	63.6	54.7
13172-022	BB	0.370	80.3	69.1
11005	WOB	0.182	39.4	34.0
11051	WOB	0.034	7.3	6.3
11153	WOB	1.436	312.3	268.4
11188	WOB	0.264	57.4	49.4
11193	WOB	0.410	87.7	76.6
11273	WOB	0.455	99.1	85.0
11538	WOB	0.967	210.6	180.7
11563	WOB	0.739	161.1	138.1
12132	WOB	0.040	8.6	7.4
12139	WOB	0.020	4.3	3.7
12443	WOB	0.002	0.4	0.3
12552	WOB	0.007	1.6	1.3
12681	WOB	0.174	37.7	32.5

TCEQ ID	Watershed	Flow[1] MGD	Estimated Biosolids[2] Using Mass Balance (dry metric ton/yr)	Estimated Biosolids[3] Using BGF (dry metric ton/yr)
12714	WOB	0.137	29.8	25.6
12795	WOB	0.254	55.1	47.4
13623	WOB	0.050	10.8	9.3
13689	WOB	0.376	81.6	70.3
10495-076	WOB	9.868	2150.1	1844.1
12552-002	WOB	0.004	0.9	0.8
Summary Statistics				
	Average	0.647	140.72	120.94
	Median	0.293	63.56	54.70
	Total	34	7458	6410
	Stdev	1.493	325.07	278.96
	Count	53	53	53

Note

1 Average Flow data from 2002 to 2003
2 Estimated Biosolids by mass balance
Using Average flow, $Y_{c,obs}$=1, Influent BOD=190 mg/L
Influent TSS=210mg/L, $Y_{n,obs}$=0.12, VSS/TSS=0.85
3 Estimated Biosolids by BGF

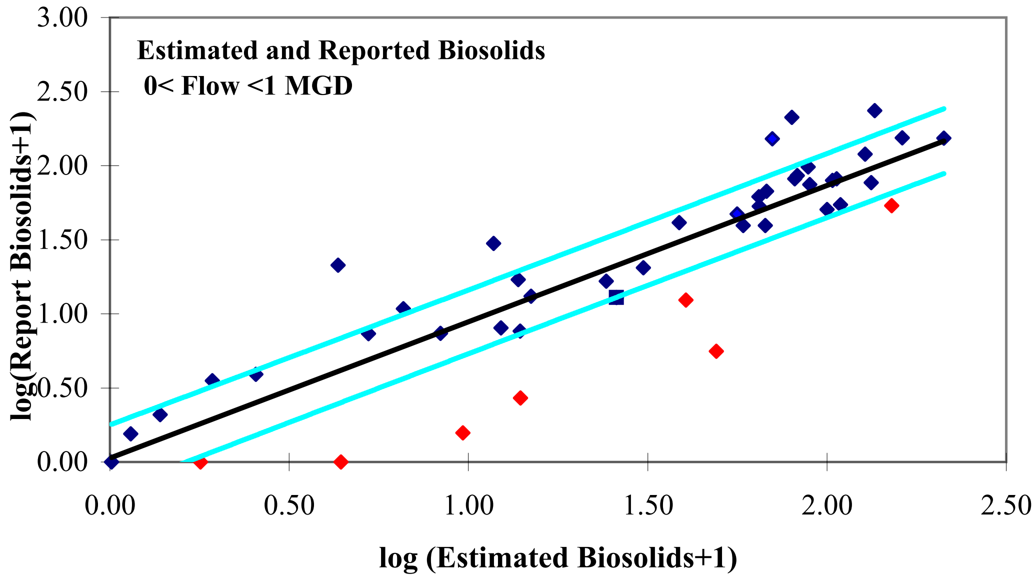


Figure 3.3 Comparison of Estimated and Reported Biosolids (Flow < 1 MGD)

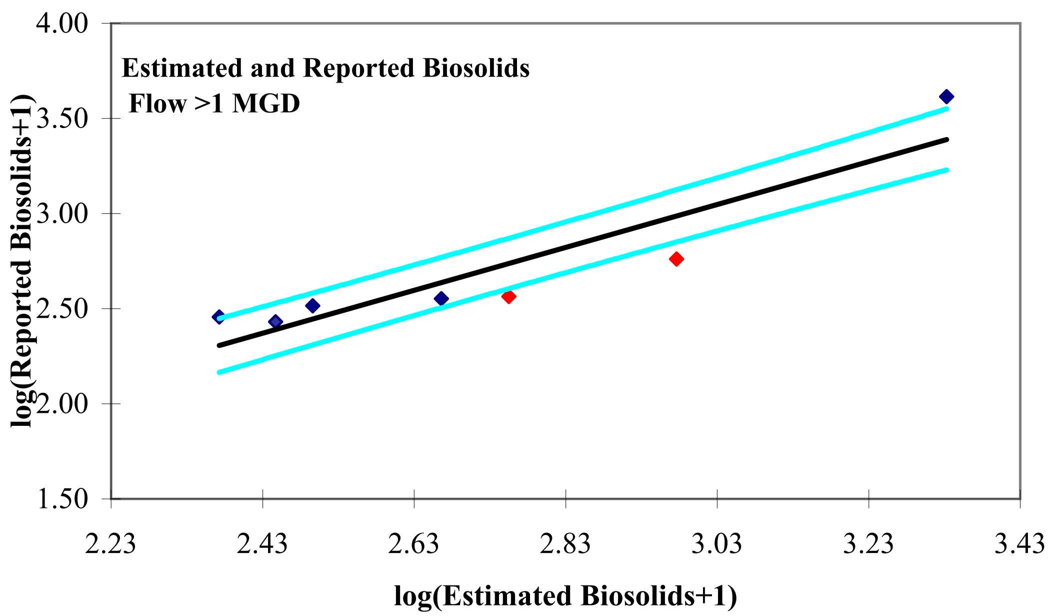
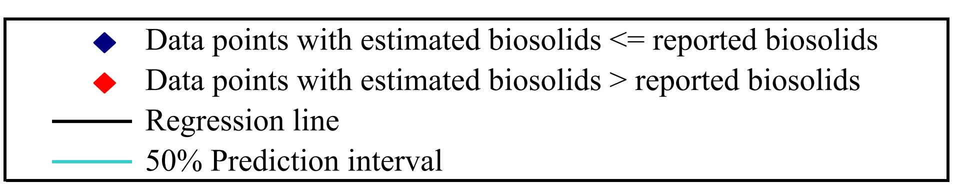


Figure 3.4 Comparison of Estimated and Reported Biosolids (Flow > 1 MGD)



balance approach, it was necessary to develop a statistical method to determine which plants had reported values that differed significantly from the calculated average value.

The slopes and intercepts of each of the two regression lines were statistically compared by developing a prediction interval in order to determine the relationship between estimated and reported biosolids. A 100(1-α)% prediction interval for each paired set of data, x_i = log (estimated biosolids +1), y_i = log(reported biosolids+1), is calculated using Equation 3-8.

$$\hat{y} \pm t_{a/2} s \sqrt{1 + \frac{1}{n} + \frac{(x_p - \bar{x})^2}{SS_{xx}}} \qquad \text{(Eqn 3-8)}$$

Where:

ŷ is the log(reported biosolids+1) of the least squares line,
s is the estimated standard error of regression model for estimated and reported data
n is the number of the data set
α is the significance level
x_p is defined as a specific value of log (estimated biosolids +1).
SS_{xx} is defined in Eqn 3-9

$$SS_{xx} = \sum x^2 - \frac{\left(\sum x\right)^2}{n} \qquad \text{(Eqn 3-9)}$$

Where:

$\bar{x}$ is mean of the estimated biosolids value
$t_{\alpha/2}$ is based on (n-2) degrees of freedom

The prediction interval significance level is most often set to be 50%. Therefore, the 50% prediction interval is the range for a given estimated value when there is a 50% probability that the value is in this range. As can be seen in Figure 3.3 and 3.4, seven plants with flows less than 1 MGD have estimated biosolid values more than reported and fall outside the 50% prediction interval, whereas only two plants with flows greater than 1 MGD fit in that category.

A summary of the plants that fall outside of the lower prediction interval is shown in Table 3.6 as well as the permit number, plant name, flow data, estimated sludge, and reported biosolids. All plants listed in Table 3.4 exhibit reported values at least 27% less than those estimated by the mass balance method, with 67% of those plants exhibiting reported values that more than 62% are lower than their reported counterparts. It is important to note that the plants in Table 3.6 have not had a documented solids release nor does the fact that the reported sludge is much less than the estimated value indicate with certainty that these plants have improperly managed their sludge. It is merely an accounting of the plants that exhibit reported values much less than the estimated values. If the 80% prediction interval was examined, all plants would fall within the interval.

Table 3.6 Wastewater treatment plants Where Estimated Biosolids > Reported Biosolids

Permit #	Plant Name	Flow rate (MGD)	Estimated Biosolids[1] (Met ton/yr)	Reported Biosolids (Met ton/yr)
13245	GRAND LAKE MUD NO. 4	0.23	48.97	4.58
13484	NORTHWOODS INDUSTRIAL PARK WWTP	0.06	12.96	1.774
12132	WHITE OAK OWNERS ASSOCIATION	0.04	8.64	0.572
11005	CHAMP'S WATER COMPANY	0.18	39.42	11.37
11598	HARRIS COUNTY MUD NO. 61	0.69	150.41	50.61
10495-109	CITY OF HOUSTON	4.35	946.31	575
11290	JACKRABBIT ROAD PUBLIC UTILITY DISTRICT	2.62	567.67	365.57
12858	GEORGE BUSH PLANT	0.97	210.63	152
12830	ROBINSON, J.W.	0.004	0.8	0

[1] Estimated using mass balance approach

CHAPTER 4

WATER WITHDRAWALS AND DIVERSIONS

While Houston is in a relatively water-rich part of Texas, increasing population growth and the need to convert entirely from groundwater to surface water sources has increased the demand for water. In years to come, this demand is projected to increase. Increased demand can be expected to result in increased diversion and use of water from bayous in the Houston area, including Buffalo and Whiteoak Bayous. These reductions in flow may affect bacteria concentrations. This chapter presents analysis of the effects of water withdrawal on the bacteria concentrations and loads in Buffalo Bayou and White Oak Bayou and presents recommendations intended to maintain a balance between withdrawals and water quality. It includes a review of how water rights and availability are regulated and a summary of current water rights permits and recent applications for diversion and reuse of wastewater. The chapter also includes an analysis of how these applications may translate into changes in stream flow and a preliminary simulation using the HSPF bacteria model to assess the effects of the changes in flow.

4.1 REGION H WATER AVAILABILITY MODEL (WAM)

Texas water law is based on seniority—first in time, first in right. If there is water available in a stream that has not been appropriated, the TCEQ can issue a water right for a specified amount of flow, subject to restrictions that may be necessary to protect other right holders and the environment. The concept is similar to other natural resources such as minerals where a right to extract the resource is obtained, subject to certain limitations. Before a water right is issued, the

TCEQ must determine that the flow exists, that a right to the flow has not previously been issued, and that the environment will be protected.

To assess the availability and reliability of flows, the most recent version of the Water Availability Model (WAM) is typically employed. This model is based on the Water Rights Analysis Program (WRAP) originally developed by Dr. Ralph Wurbs at Texas A&M University in 1996. The model was adopted by the Texas Commission on Environmental Quality (TCEQ) in accordance with Senate Bill 1 (passed by the Texas legislature in 1997) to evaluate the availability of water sources through time. WAM is designed to simulate management and use of stream flows and reservoir storage in one or more river basins under the water right appropriation system. The model is set up using monthly average flows and tracks reservoir storage, diversions and returns on stream flow at a number of control points.

Basin hydrology is assumed to be a repetition of the historical period of record (1940 to 1996 in the Region H case). In general, the model gives the full amounts of all permitted senior water rights as long as there is flow available. The model is used to aid in a number of planning decisions, one of which is determining if there is water available for appropriation. The most recent water availability modeling for the San Jacinto River Basin, which includes Buffalo and White Oak Bayous, was produced under contract to the TCEQ by Espey, Padden Consultants (EPC, 1999).

The WRAP model works by performing a water accounting simulation utilizing a series of loops. Specifically, the WRAP simulation is composed of the following loops:

- **Loop 1:** The input data including water rights, storage-area tables, basin configuration, use types, return flow factors, and gains and losses in the basin are read into the program and water rights are then ranked in priority order.

- **Loop 2:** The hydrology records, inflow and evaporation, are read and adjustments for negative incremental flows and December return flows (made to January flows) are performed in an annual loop.
- **Loop 3:** A monthly loop is performed in which net-evaporation-precipitation adjustments are made, spills are computed based on monthly varying storage capacities, flow adjustments for constant inflow/outflows are computed, a water right loop is performed, and then control point and reservoir records are developed.

The water rights loop is run for each water right in priority order and is composed of determining the amount of water available for each water right, checking unappropriated and regulated flows, making diversions, reservoir releases, and return flows, adjusting available flows at all control points, and creating output records for each water right.

For the Buffalo and Whiteoak simulations a key factor is the naturalized flows. Whenever possible, naturalized flows at the primary control points are based on available flow records using the methodology described below. A primary task undertaken in a water availability study is to calculate naturalized flows.

Naturalized flow data are based on historical flows, adjusted to remove the effects of human activity. A general equation for naturalized flow is:

Naturalized Flow = Historical Flow + Upstream Diversions – Upstream Return Flows + Changes in Upstream Reservoir Contents + Upstream Reservoir Evaporation

The elements of the equation are determined as follows:

- ***Historical Flow*** – Flow recorded at USGS flow gages.
- ***Upstream Diversions*** – Upstream diversions as recorded in TCEQ records (or as estimated when records are missing).
- ***Upstream Return Flows*** – Upstream return flows as recorded in TCEQ records (or as estimated when records are not available). Return flows under 0.2 MGD were ignored in the San Jacinto Basin study.
- ***Changes in Upstream Reservoir Contents*** – Changes in contents for major upstream storage reservoirs are normally considered. Flood control reservoirs such as Barker and Addicks are not intended to have an impact on water availability and were not considered. Content changes for reservoirs with less than 5,000 acre-feet of conservation storage (e.g. stock tanks and SCS reservoirs) were also not considered. While these smaller reservoirs were not counted as storage, they do have some effect on smoothing out the flows, at least in Buffalo Bayou.

In the San Jacinto Basin study, monthly average wastewater return flows were reported to be obtained from the agency for the period 1978 to 1996 and subtracted from the gaged flows at the selected control points. The gages used as control points for this study were:

- BB near Addicks (Gage # 08073500 at Dairy Ashford)
- BB at Houston (Gage # 08074000 at Shepherd)
- WO at Houston (USGS Gage # 08074500 at Heights Street)

A key aspect is that the model works on the basis of monthly average flows. Naturalized flows for the three gage locations include the higher daily flows from a runoff event in the monthly averages. The practical effect of using a monthly average is that the values are not as low or as high as the daily values. For larger river systems this is generally not a concern, but with smaller systems the difference between daily and monthly values can be significant.

Figures 4.1 and 4.2 show the naturalized flows for the Dairy Ashford and Shepherd gages in Buffalo Bayou and Figure 4.3 shows the flows for the Heights gage in Whiteoak Bayou. In each case the yearly average and minimum monthly flows are shown. At each location the annual average flow appears to show no temporal trend while there does appear to be an increase in the minimum monthly flows. This will be discussed in more detail in the next section.

Both BB gages are below the Barker and Addicks flood control reservoirs, while the WO gage is not affected by reservoirs. These reservoirs smooth the flow in BB and extend the duration of events over what would have been the case. In some months this will mean flow that is stored in the reservoir would be carried into the next month, when that would not have been the case without the reservoirs.

4.2 WATER RIGHTS IN BUFFALO AND WHITEOAK BAYOUS

The right to withdraw water from surface water sources considered State of Texas waters, including creeks, rivers, and bays may be obtained through the issuance of a permit by the state of Texas. The applications for this right must be approved by the Texas Commission on Environmental Quality (TCEQ) after a study has been performed to analyze the effects of the withdrawal upon existing water rights, bays and estuaries, and to determine the availability of the requested water. There are several current water right permits that have been granted in the Buffalo and Whiteoak

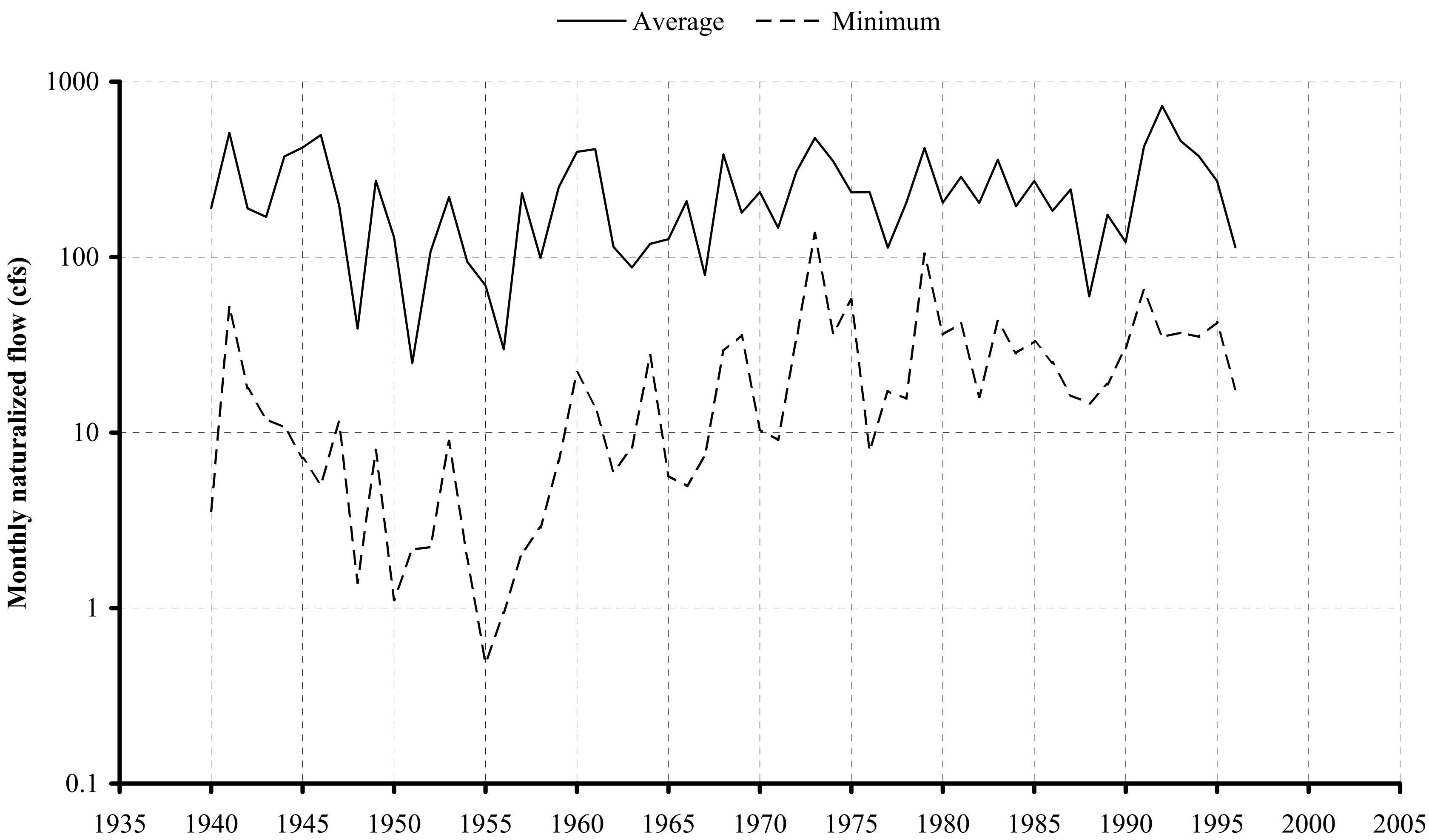


FIGURE 4.1
Naturalized Flows at USGS Gage 08073500, Buffalo Bayou at Dairy Ashford Road

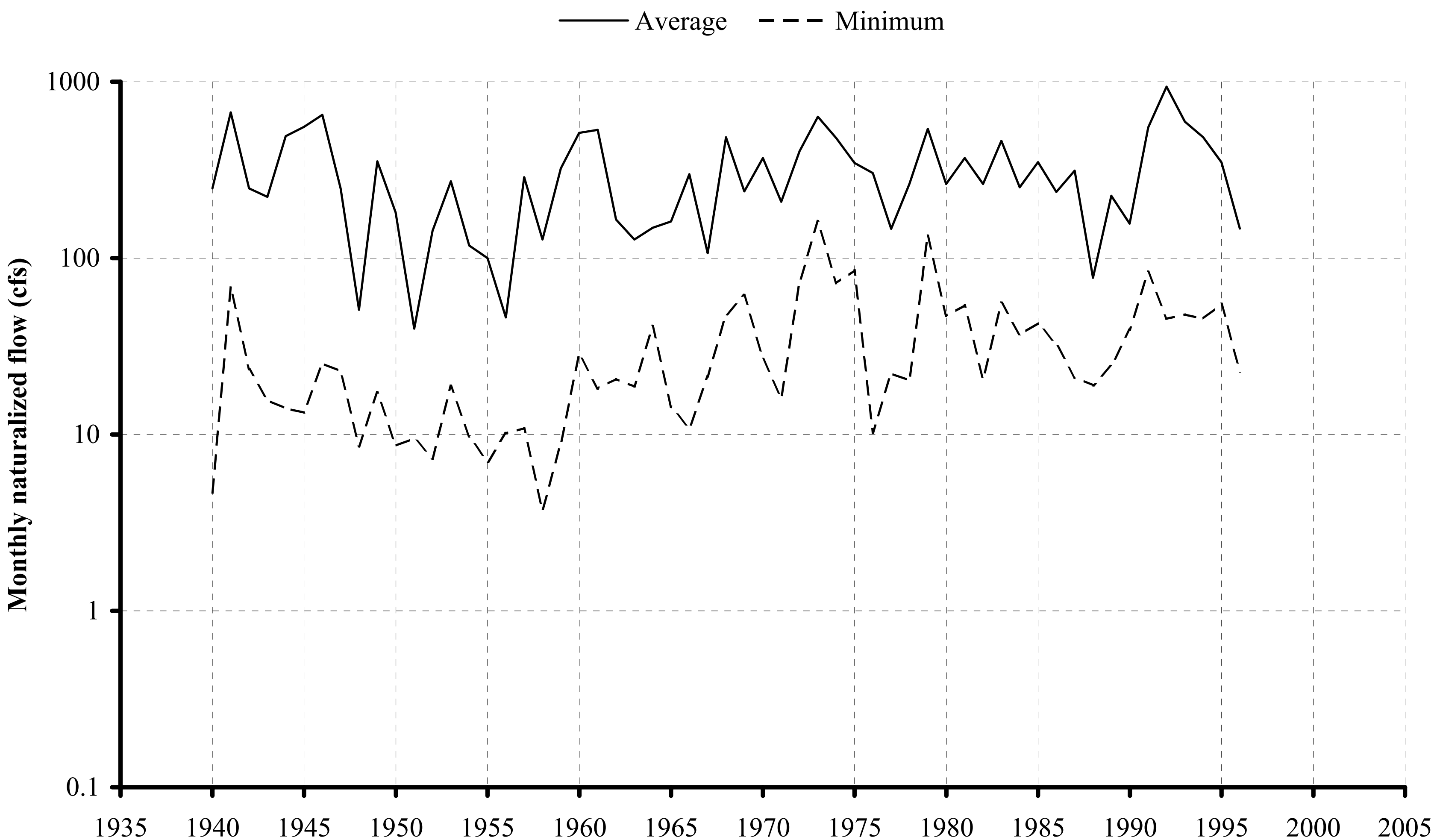


FIGURE 4.2
Naturalized Flows at USGS Gage 08074000, Buffalo Bayou at Shepherd Drive

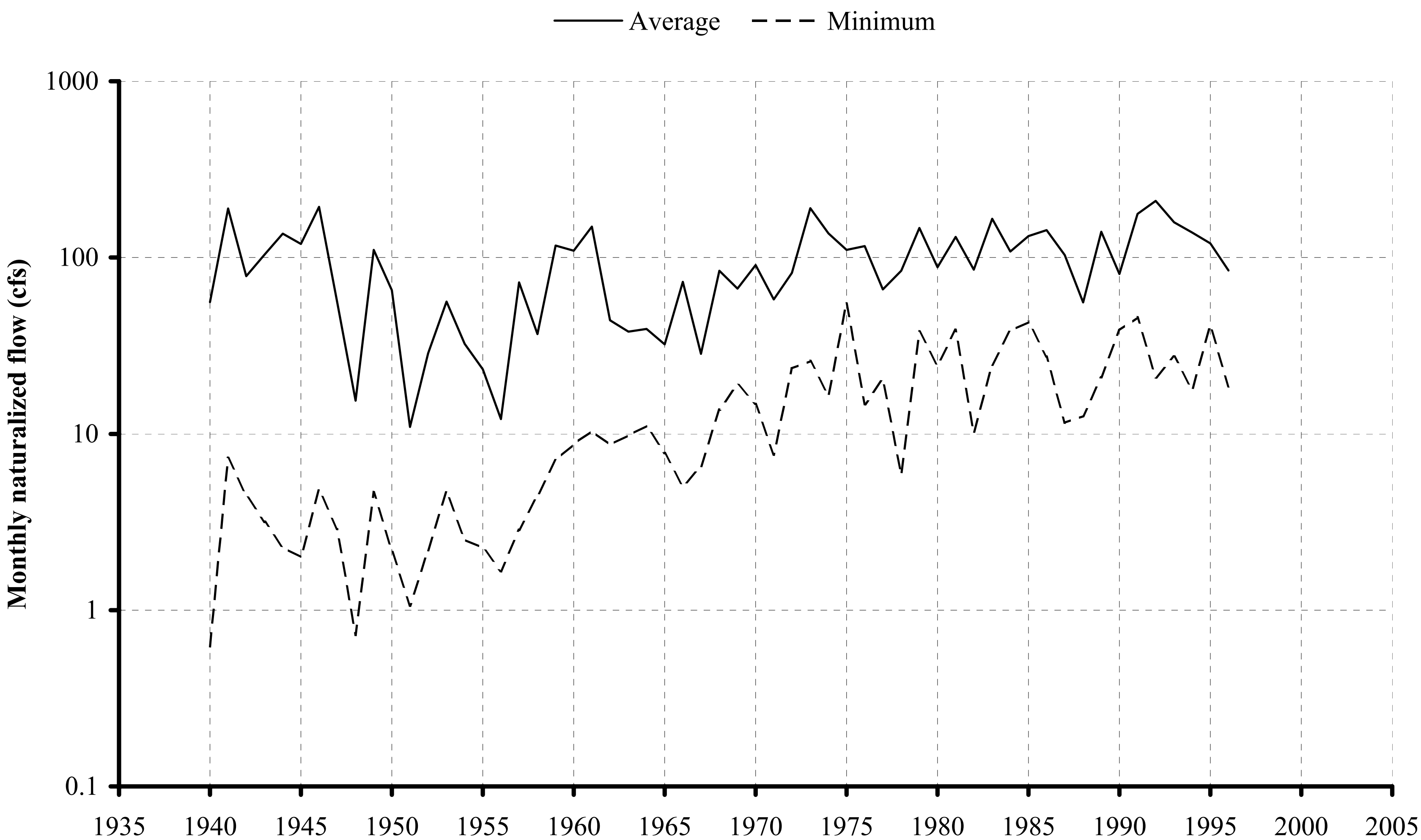


FIGURE 4.3
Naturalized Flows at USGS Gage 08074500, White Oak Bayou at Heights Blvd

Bayou watersheds and there are also applications that have been submitted to request that right. This section provides a summary of those permits.

4.2.1 CURRENT WATER RIGHT PERMITS

August 31, 2004. Fifteen active permits provide for the use of water from Buffalo Bayou and three for water from White Oak Bayou. A list of the active permits and information concerning each has been included in Table 4.1. The water rights for Buffalo Bayou listed in these permits range from 19 acre-ft/year to 800 acre-feet per year, with a total diversion volume of 2,664 acre-ft/yr (spread uniformly over the year, this volume is equivalent to 3 cfs). Those for White Oak Bayou specify much less significant amounts, with a maximum of 230 acre-ft/year for an individual permit and a total of 365 acre-ft/yr. Most of the permits have been issued for recreational and irrigation purposes.

4.2.2 PENDING WATER RIGHTS APPLICATIONS

The base flow in Buffalo (BB) and White Oak (WO) Bayous is maintained by wastewater discharges. In general the quality of this water is very good. Because the quality and reliability of this water and the fact that Texas surface water law allows individuals to obtain rights to unappropriated surface water, there is the possibility that the bayou flows could be claimed by others with an interest other than the benefit of the City at large. To avoid that possibility, the City of Houston (COH) took action in January, 2004, and submitted the following:

- Application for Water Right 5826 more than 150,000 acre-ft of unappropriated water in the San Jacinto Basin, and

Table 4.1 Active Water Rights Permits

WR Number	Permit #	Type	WR Issue Date	Priority Date	Owner Name	Owner Type	Amount in Ac-Ft/Yr	Use	Stream Name
4066	3779	Application/Permit	12/9/80	8/11/1980	MARIAN W FLEMING	Individual	45	Irrigation	Bear Creek
3983		Certif of Adjudication	3/14/86	12/31/1916	HAROLD & JESSE FREEMAN	Individual	800	Irrigation	Bear Creek
3982		Certif of Adjudication	3/14/86	6/30/1952	CINCO RANCH EAST DEVELOPMENT	Organization	45	Irrigation	Buffalo Bayou
3984		Certif of Adjudication	3/14/86	6/30/1963	LENOIR M JOSEY INC	Organization	26	Irrigation	Langham Creek
3986		Certif of Adjudication	3/14/86	9/11/1972	MUSEUM OF FINE ARTS	Organization	19	Irrigation	Buffalo Bayou
3985		Certif of Adjudication	3/14/86	1/30/1978	RIVER OAKS COUNTRY CLUB	Organization	460	Irrigation	Buffalo Bayou
5209	5209	Application/Permit	4/6/89	12/15/1988	INWOOD FOREST GOLF & CTRY CLUB	Organization	230	Irrigation	Whiteoak Bayou
5209	5209	Application/Permit	4/6/89	12/15/1988	INWOOD FOREST GOLF & CTRY CLUB	Organization		Recreation	Whiteoak Bayou
5257	5257	Application/Permit	5/29/90	9/13/1989	LAKESIDE COUNTRY CLUB	Organization	175	Irrigation	Buffalo Bayou
5257	5257	Application/Permit	5/29/90	9/13/1989	LAKESIDE COUNTRY CLUB	Organization		Recreation	Buffalo Bayou
5257	5257	Application/Permit	5/29/90	1/9/2001	LAKESIDE COUNTRY CLUB	Organization	175	Irrigation	Buffalo Bayou
5332	5332	Application/Permit	3/19/91	11/28/1990	PINE FOREST COUNTRY CLUB	Organization	378	Irrigation	Bear Creek
5332	5332	Application/Permit	3/19/91	11/28/1990	PINE FOREST COUNTRY CLUB	Organization		Recreation	Bear Creek
5336	5336	Application/Permit	3/19/91	12/5/1990	HOUSTON COUNTRY CLUB	Organization	175	Irrigation	Buffalo Bayou
5336	5336	Application/Permit	3/19/91	12/5/1990	HOUSTON COUNTRY CLUB	Organization		Recreation	Buffalo Bayou
5565	5565	Application/Permit	2/20/98	12/19/1996	OUR SAVIOR LUTHERAN CHURCH	Organization	60	Irrigation	Whiteoak Bayou
5624	5624	Application/Permit	9/14/99	4/6/1999	FARTHER POINT POA INC	Organization	402	Other	Buffalo Bayou
5762	5762	Application/Permit	9/3/02	2/12/2002	MEMORIAL PARK GOLF COURSE	Organization	184	Irrigation	Buffalo Bayou
5789	5789	Application/Permit	7/7/03	10/9/2002	LAKESIDE CLUB	Organization	75	Recreation	Whiteoak Bayou

Notes:
1. The active water rights data from TCEQ does not specify exact locations (only stream names) of the diversion points, any obvious diverersions occurring in the Houston Ship Channel hav
2. Explanations of fields at <http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/ddiction_2004.pdf>

- Application for Water Right 5827 requesting authorization to divert existing effluent return flows, totaling approximately 600,000 acre-ft/year (full permitted flow from 35 plants, less 5% carriage loss).

These applications are undergoing technical review, and this review has not been completed as of August 31, 2004. If the water rights and authorizations are issued, the priority dates will be set and Houston will not have to be concerned with claims on the water from outside interests. Further, the City will be authorized to divert the bayou water for purposes such as irrigation, and with suitable treatment, for use as a municipal water supply. These permits will be discussed in more detail in Section 4.2.3.

In addition to the Houston applications, there are a number of other water rights in the basin that have been issued. The Harris County Flood Control District (HCFCD) has a number of stormwater detention facilities that are being converted to wet ponds for water quality purposes. To maintain the water level in dry periods, the HCFCD is applying for water rights permits to divert water from the bayous. To date none have been prepared for the BB or WO watersheds, but one has been prepared for Halls bayou and another is under preparation for Armand Bayou. In Halls Bayou an Application for Permit to Appropriate Public Water for HCFCD's Keith Wiess Park Detention Facility (HCFCD ID # P518-02-00-Y001) was prepared in June 2004. The draft application requests permission to divert water from Halls Bayou through a 24" gravity storm sewer pipe to a proposed off-channel reservoir. The proposed diversion rate was 2,290 ac-ft/year. On an average basis this is only about 3 cfs, but the diversion would be primarily during dry periods so the rate during dry weather periods could be higher.

4.3 IMPACT OF WWTP FLOW REDUCTIONS UNDER DIFFERENT STREAM FLOW AND SEASONAL CONDITIONS

If water is either diverted from the bayous or directly from WWTPs, the uses for that water will have certain patterns and responses to seasonal conditions that must be considered. Three types of uses are considered: irrigation, industrial cooling water, and domestic supply. The following paragraphs describe the expected patterns in the uses of the requested water. These potential impacts are based upon general reductions in flow, not any specific scenario.

4.3.1 IRRIGATION USE

Irrigation water needs vary greatly with season and antecedent moisture. Needs during the winter or non-growing season can be expected to be a small percentage of the peak growing season needs. Similarly, irrigation needs following rains will be very small. Because of this variability, irrigation needs can be hard to supply, as capacity is needed for the peak flow, but the average flow will be much less than the peak flow. Reduction of flow due to diversions and reuse during the growing season and during extended dry periods could negatively affect irrigation use.

4.3.2 INDUSTRIAL USE

Industrial cooling water needs will tend to be more constant but will typically have a seasonal pattern. For example, if the need is for cooling tower makeup for an electric power facility, the need will be greatest in the summer, when electrical generation needs are highest. But if the power plant is a base load unit (i.e. operates near full capacity all year), there will be little seasonal difference. The only difference would be in winter there is more cooling directly by radiation and thus there would be less need for evaporative cooling, with attendant water consumption. This type of water is the easiest to supply, but reductions in flow during the summer months may reduce flows to the point that there is inadequate water supply for industrial users.

4.3.3 DOMESTIC USE

Domestic use, whether as a purple pipe system for lawn irrigation and toilet flushing or as a component of potable water, will tend to have a strong seasonal variation reflecting differences in irrigation use. There will also be daily and weekly variations reflecting domestic activity. These differences in use rates will mirror the differences in wastewater generation at domestic WWTPs. Thus, these uses might suffer when diversions and reuse of effluent are in full force.

4.4 MODELING OF DRY WEATHER CONDITIONS

This section addresses how the model was modified to improve performance at the low flow range. The model was formulated to perform well in a typical situation where frequent rains bring short inputs of runoff that have high indicator bacteria concentrations. As high bacteria levels are a major concern, the modeling effort was centered on this process.

The critical condition for the increased diversion situation is one where there have been no rains and flows are getting progressively lower. To address this point, the model was first run with a special input condition with no rains and allowed to reach equilibrium. In this case the only flow in the model is from wastewater discharges. As these are input at their average self-reported level, the flows are larger than would actually exist in dry weather conditions. These wastewater flows were stepped down in the model and bacteria results were observed.

In parallel, a search is ongoing through the available data to identify samples collected after prolonged dry periods—two weeks without any rain recorded in the watershed will be an initial estimate of the time the bayous require to achieve equilibrium. Data that meet that requirement are being assembled and analyzed for a number of stations in both bayous.

4.5 HSPF ASSESSMENT OF WATER WITHDRAWALS

An HSPF model has been developed to simulate the transport of dissolved and sediment-associated *E. coli* within Buffalo Bayou and White Oak Bayou. The HSPF program was designed to simulate the hydrological and water quality processes that occur in watersheds of interest. The models created for each bayou include the contribution of point and non-point sources into the bayous, as well as, parameters that incorporate meteorological data, soil and reach/reservoir characteristics, sediment scour/deposition, and adsorption and transfer rates. These models were modified to assess the impact of water withdrawals and reuse as proposed by the COH in the permit applications 5826 and 5827.

To incorporate the diversion of water into the HSPF model, each outflow demand has been designed to be withdrawn through an additional time dependent exit using the OUTDGT time series function. The function allows the model to withdraw a volume that has been specified by one or more time series according to diversion requirements. The withdrawals have been designed to occur at the RCHRES module that simulates the hydrological processes within a particular reach of the bayou.

Watershed Data Management files (WDM) have been created to input the time dependent volume of withdrawn water into the HSPF model. The time series have been developed to reflect variations throughout the period of interest at hourly intervals. Several data series have been created to simulate possible scenarios. These include the largest volumes of withdrawal allowed by each application individually and cumulatively, as well as, the amounts predicted by past trends and

WWTP discharge data. The WDM files have been linked to separate HSPF program files (each incorporating the withdrawals for a specific scenario) using the external sources block.

For each point of diversion, the mass-link function has been utilized to direct the flow to a particular exit. The exits have been separated so that the volumes that flow through each can be analyzed separately at hour intervals. In addition, the dissolved and suspended sediment-associated *E. coli* carried through each exit can be analyzed separately. A step-by-step procedure that describes and details the programming steps taken to incorporate each diversion into the HSPF model has been included in Appendix D.

CHAPTER 5

SEDIMENT CONTRIBUTIONS

Sediments and other suspended solids play a vital role in the formulation and analysis of bacterial topics. First, indicator bacteria are "suspended solids" in that they are almost all removed by the standard filters that are employed to define the term. As discussed in earlier sections, indicator bacteria are an important part of stream sediments. This chapter first reviews local data and literature on bacteria in soils and sediments, much of it collected recently for the Harris County Flood Control District (HCFCD). It then describes the process and results of tests designed to assess the possible role of wastewater treatment facilities on stream sediment characteristics. Finally, the role of settling of particulate matter is described in laboratory tests that track both bacteria and TSS levels under controlled settling conditions. The chapter concludes with a discussion of bacteria and sediment contributions and interactions.

5.1 LITERATURE AND LOCAL DATA

As part of a larger effort dealing with maintenance of drainage structures, the HCFCD had data collected on area stream sediments and soils and reviewed literature relevant to the topic. This section briefly draws from that work and summarizes key findings of that effort relevant to the indicator bacteria TMDL topic. The main data collection and findings are reported in the text, and a portion of the annotated bibliography dealing with soils, sediments and bacteria is included as Appendix E.

Soil consists of a complex mixture of mineral particles in a range of sizes and varying amounts of organic matter. The organic matter is both in particulate form and sorbed to the mineral particles. The size range of the particles is frequently used to classify soils as sand, silt, or clay:

Particle	**Diameter (mm)**
Medium sand	0.5 – 0.25
Fine sand	0.25 – 0.05
Silt	0.05 – 0.002
Clay	Below 0.002

Also, organic content is a useful measure to categorize soils. Soil scientists characterize organic matter in terms of humus content (organic matter that has undergone extensive decomposition) as well as fresh organic matter (Miller, et al., 1966). Miller et al. suggests that organic matter represents as much as 8% by weight of a good topsoil. The organic matter content typically is much lower below the topsoil layer, or in upland areas that are eroding.

The richest and most desirable soils for growing plants are those with a higher organic content to help hold moisture and a rich culture of microorganisms to convert the organic matter to a form that can be used most efficiently by plants. These are the soils produced by compost piles, commonly used by gardeners and also common in good top soils. Before chemical fertilizers were commonly available, farmers practiced rotation of land between crop and pasture to maintain the needed balance of nutrients and organic matter.

Soil microbes serve a similar function to those in the intestinal tract in recycling organic matter and frequently encounter similar ambient conditions. For example, soils are frequently anaerobic like the intestine, and frequently have temperatures in Harris County that are similar to those of mammals and birds. As a consequence, it is not surprising that bacteria and other microorganisms indicative of excrement can be detected in soils. Soil organisms include a wide range of bacteria, fungi, actinomycetes, algae, protozoa, nematodes, earthworms, and larger animals such as insects. The number of bacteria in soils is impressive, ranging from 0.3 to 95 million cells per gram of soil, and representing on the order of 500 pounds live weight per acre (Miller, et al., 1966). As would be expected with a rich and diverse microbial culture, some are capable of causing illness, the definition of a pathogen.

The soils that accumulate in study area streams have some similarities to desirable garden and agricultural soils. They have organic matter from the watershed, such as leaf litter and lawn clippings, and other sources of organic matter such as animal and bird droppings that are washed from the watershed during rains.

5.1.1 LITERATURE REVIEW

A literature review was conducted to assist the HCFCD, and an annotated bibliography was produced. A portion of the annotated bibliography that relates to bacteria levels in soils and sediment was extracted and is included as Appendix E.

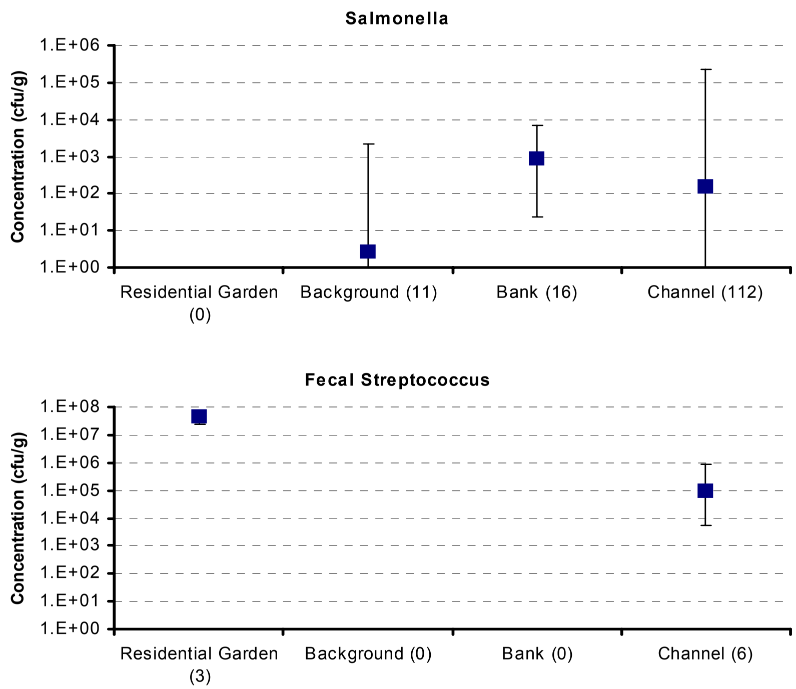
5.1.2 HCFCD SAMPLING RESULTS

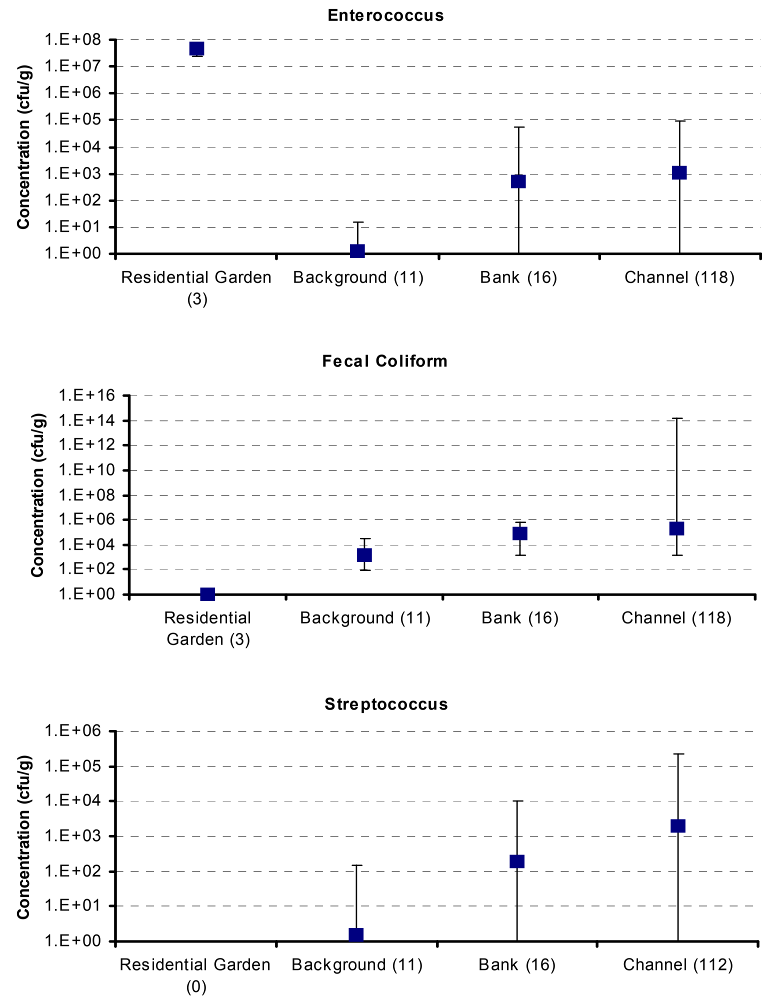
As a part of efforts to understand and manage the area drainage channels, the HCFCD had a number of soil and sediment samples analyzed for common bacterial indicators and pathogens. Malcolm Pirnie (2003) supervised the collection of most of the samples, and several contract laboratories were employed. PBS&J was involved in analyzing and presenting the data. Most of the soil samples were analyzed for fecal coliform, *Enterococcus*, *Streptococcus*, fecal *Streptococcus*, and *Salmonella*. All are common bacteria forms that are widely used as indicators, and can have enteric sources. These microorganisms can also be found in the environment and can survive for substantial times or sometimes grow in soils (Gerba, 1975, cited in NRC, 2002, p. 217). A number of different test procedures were employed and all involved adding water to make the soil a liquid sample and analyzing with liquid methods, similar to those employed in this TMDL study. Results were provided in colony forming units/g of soil. It was not specified whether it was dry weight or weight as sampled.

Figure 5.1 presents a summary of the sampling results obtained, grouped by general location. Most of the samples were collected from drainage channel bottoms, with a smaller number from the channel bank. Samples were also collected to represent background, and three residential garden samples were included. The background samples (10 samples and one QC sample) were collected from a forested area of Greens Bayou west of Sheldon Reservoir. The site was reported to have been selected to have minimal effects of human or domestic animals. About 80% of the sampling area was reported to be covered by pine trees. No information on soil moisture, silt-clay-sand characteristics, or organic content was available. Presumably, these are upland sites rather than drainage channels. The residential garden sampled was at the corner of Thomasville Drive and Rockville Drive in the Bellmeade Subdivision located near the headwaters of Greens Bayou and FM 1960.

The results suggest a substantial amount of variation with each sample group, with the difference between maximum and minimum values often exceeding three orders of magnitude. It appears that for most parameters the channel and bank samples had somewhat higher geometric mean concentrations than the background soil samples, but there was overlap in all the parameters. The highest values for *Enterococcus* and Fecal *Streptococcus* were the garden samples, but it is not clear why these samples would have low Fecal Coliform results.

Differences in levels can be expected, depending on the soil used for comparison, whether the sediment from the channels was sampled immediately after a rain or some time later, and the moisture and organic content of the sediment and comparison soil. There are a host of variables that





NOTES:
1.Boxes represent geometric mean of values. Geometric means were calculated using one when zero was reported.
2.T-bars show minimum and maximum values.
3.Values in ( ) indicate number of samples.
4.cfu = colony forming units
5.g = gram

Figure 5.1 – Bacteria Sampling Results, November 2002 to September 2003

could affect a specific comparison. These data are not extensive enough to allow a definitive conclusion on which areas have higher concentrations and begin to explain the sources of variation in the data. They are useful, however, in documenting that residential garden, drainage channel, bank, and upland background soils in Harris County contain significant levels of indicator organisms and pathogens. This is important information because it may provide an explanation for the overall elevated levels of indicator organisms typically found in area bayous.

5.2 WWTP EFFECTS ON STREAM SEDIMENTS

Effluent from WWTPs is treated to remove most oxidizable organic matter and disinfected to limit bacterial contributions. In theory, one would expect a discharge of relatively clean water to have little potential to produce a significant or detectable environmental effect. At the same time, indicator bacteria concentrations in area bayous tend to be high. A theory has been suggested that WWTPs may not manage their biological solids effectively and release solids that are very high in fecal bacteria. These solids would presumably settle and contaminate the stream sediments downstream.

To test that theory, an experiment was designed to compare sediment conditions in six small streams, three with and three without WWTPs. Sediment samples were collected at two locations along each stream, with three samples being collected over time. For the streams with WWTPs, both locations were downstream of the WWTPs. Figure 5.2 shows the locations of the six streams, the WWTPs, and the sampling locations. Table 5.1 shows the average values of Discharge Monitoring Report (DMR) data of the WWTPs from January 2004 to April or May 2004. The data indicate low TSS and $CBOD_5$ in the effluents of all the plants. Ammonia-N is also low except for Permit No.

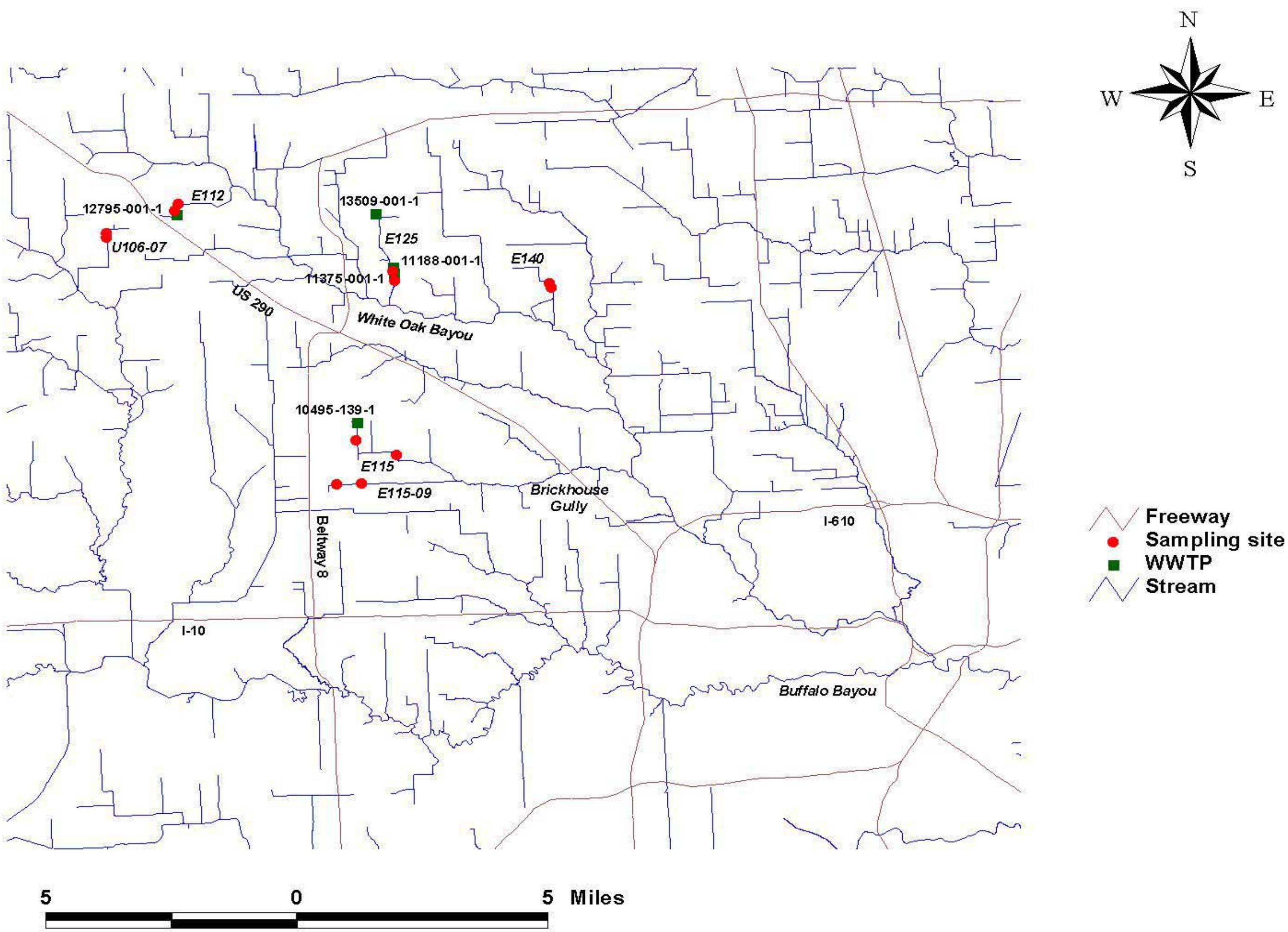


Figure 5.2 Locations of WWTPs and Sampling Sites for WWTP Effects on Stream Sediments

TABLE 5.1
DISCHARGE MONITORING REPORT DATA

Stream	Permit	Reporting period	Flow MGD	DO mg/L	pH SU		TSS mg/L	$CBOD_5$ mg/L	NH_3-N mg/L	Chlorine residual mg/L	
					min	max				min	max
E115	10495-139	Jan to May '04	0.551	7.76	7.82	8.18	5.6	2.2	0.14	1.16	3.32
E125	13509-001	Jan to May '04	0.025	4.04	6.82	7.08	7.4	3.0	2.53	1.08	3.62
	11188-001	Jan to Apr '04	0.204	6.88	6.66	7.46	5.2	2.7	0.13	1.14	3.35
	11375-001	Jan to Apr '04	0.049	7.20	7.21	7.85	4.6	2.7	0.10	1.00	4.00
E112	12795-001	Jan to May '04	0.301	6.13	6.83	7.49	10.4	2.8	0.12	1.08	3.39

1. Except for pH and chlorine residual, values shown are averages of monthly average values of the reporting period.
2. For pH and chlorine residual, values shown are averages of monthly max/min values of the reporting period.
3. Storet code for parameters: Flow 50050, DO 00300, pH 00400, TSS 00530, $CBOD_5$ 80082, NH_3-N 00610, Chlorine residual 50060.

13509 that has a very small flow. The plants do not report bacteria data. However the minimum chlorine residuals are all at or above 1 mg/L so that the bacteria concentrations are likely to be low. Based on the DMR data, these plants appear to have reasonably good effluent quality. Table 5.2 presents the results of the sediment sampling. Figure 5.3 presents the sampling results for sediment total solids and volatile solids, and Figure 5.4 shows the data for sediment moisture content and EC bacteria concentration. The upper bayou samples were collected from the nearest access point downstream of the WWTP, while the lower bayou samples were collected from at least two city blocks downstream of from the upper bayou sample. For channels without WWTP discharges, the sampling stations are at locations in the channel where the watershed drainage area is similar to the corresponding paired channel station location. The EC bacteria level is expressed in MPN/100 g wet weight.

A visual examination of the sampling results suggests there is no major difference between the streams with and without WWTPs based upon the data collected. The average volatile solids of the results with WWTPs and without WWTPs are 2.66% and 2.64% respectively, and the geometric means of the sediment EC of the results with WWTPs and without WWTPs are 37,221 and 25,543 MPN/100 g respectively. Although the EC values with WWTPs are higher than those without WWTPs, it was not possible to statistically demonstrate that the means were different due to the lack of statistical power. On the other hand, a test of variances of the two data sets indicates a difference that is significant at the 95% confidence. It may be concluded that while WWTPs certainly can influence sediment conditions, there was no differences observed in the stream samples collected.

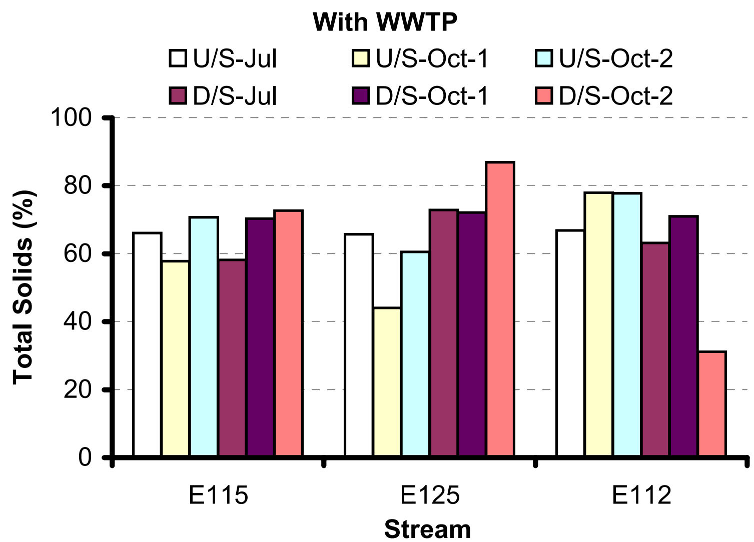
TABLE 5.2
SAMPLING DATA TO STUDY EFFECTS OF WWTP ON SEDIMENTS

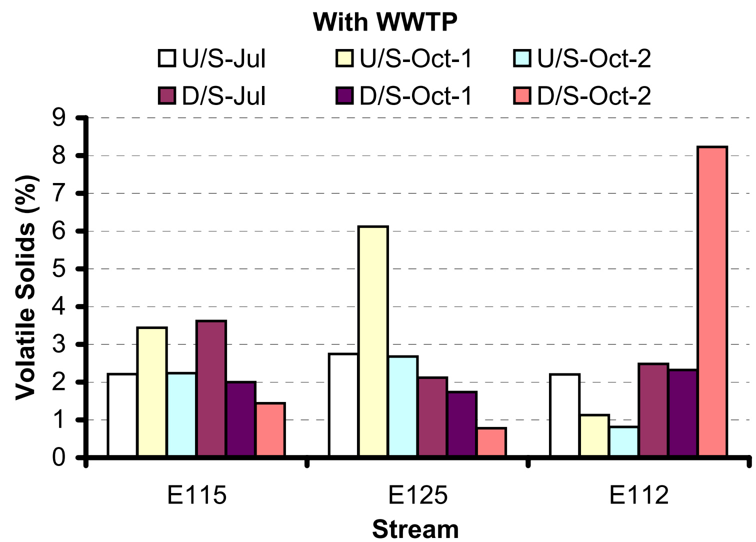
Station	Stationid	Date	Time	Depth (m)	Temperature 00010 (ºC)	Conductivity 00094 (µmhos/cm)	DO 00300 (mg/L)	pH 00400	Total Solids 81373 (%)	Volatile Solids 85207 (%)	Moisture 82003 (%)	EC 31699 (MPN/dL)	Sediment EC 31702 (MPN/100g)	Days from last rain 72053	1-d prior rain 82553 (in)	7-d prior rain 82554 (in)	Upstream WWTPs	WW Flow (mgd)
E115 #1	PBS01	07/29/04	11:20	0.390	27.29	0.702	2.60	7.45	66.10	2.21	33.90	24,890	18,828	6	0.053	2.19	10495-139	0.99
E115 #2	PBS02	07/29/04	11:05	0.304	27.05	0.705	6.00	7.33	58.20	3.62	41.80	22,470	15,709	6	0.053	2.19	10495-139	0.99
E115-09 #1	PBS03	07/29/04	10:00	0.213	27.38	0.550	1.50	6.54	63.30	3.02	36.70	34,410	23,504	6	0.053	2.19	None	
E115-09 #1 split	PBS03 split	07/29/04	10:00	0.213					67.20	2.84	32.80	16,160	9,890	6	0.053	2.19	None	
E115-09 #2	PBS04	07/29/04	10:30	0.549	27.25	0.600	2.00	6.80	70.30	2.05	29.70	31,690	18,407	6	0.053	2.19	None	
E125 #1	PBS05	07/23/04	11:05	0.244	28.50	0.809	4.50	8.20	65.70	2.75	34.30	98,300	58,947	2	0.02	0.55	13509-001	1.14
E125 #2	PBS06	07/23/04	11:25	0.427	28.15	0.751	4.06	7.61	72.90	2.12	27.10	20,420	12,054	2	0.02	0.55	13509-001	1.14
E140 #1	PBS07	07/23/04	12:15	0.335	27.49	0.743	2.02	6.96	72.40	2.02	27.60	57,600	37,539	13	0	0.12	None	
E140 #2	PBS08	07/23/04	12:39	0.335	30.92	0.686	6.03	7.52	73.40	1.55	26.60	47,860	33,043	13	0	0.12	None	
E112 #1	PBS09	07/29/04	13:05	0.610	30.37	0.505	2.20	7.02	66.90	2.20	33.10	61,300	45,746	6	0	1.81	12795-001	0.56
E112 #1 DUP	PBS09 DUP	07/29/04	13:05	0.610								148,300	110,672	6	0	1.81	12795-001	0.56
E112 #2	PBS10	07/29/04	12:35	0.457	30.07	0.498	2.40	5.99	63.20	2.48	36.80	193,500	146,060	6	0	1.81	12795-001	0.56
U106-07 #1	PBS11	07/23/04	14:16	0.122	37.55	0.734	4.88	7.14	74.80	2.13	25.20	50,075	31,258	2	0.02	0.55	None	
U106-07 #2	PBS12	07/23/04	13:40	0.274	34.38	0.755	2.64	7.20	74.00	1.61	26.00	57,410	35,143	2	0.02	0.55	None	
U106-07 #2 DUP	PBS12 DUP	07/23/04	13:40	0.274					73.80	1.59	26.20	51,485	31,516	2	0.02	0.55	None	
U106-07 #2 split	PBS12 split	07/23/04	13:40	0.274								44,905	27,488	2	0.02	0.55	None	
E112 #1	PBS09	10/06/04	14:10	0.671	28.00	0.589	5.95	8.02	78.00	1.13	22.00	93,300	71,991	0	0.08	0.95	12795-001	0.56
E112 #2	PBS10	10/06/04	13:40	0.610	28.78	0.595	7.00	7.66	71.00	2.32	29.00	101,369	66,690	0	0.08	0.95	12795-001	0.56
E112 #2 split	PBS10 split	10/06/04	13:40	0.610								78,813	51,851	0	0.08	0.95	12795-001	0.56
E115 #1	PBS01	10/08/04	10:00	0.549	25.10	0.490	3.77	7.890	57.80	3.44	42.20	24,810	19,880	0	0.93	1.98	10495-139	0.99
E115 #1 DUP	PBS01 DUP	10/08/04	10:00	0.549								24,810	19,880	0	0.93	1.98	10495-139	0.99
E115 #2	PBS02	10/07/04	12:30	0.914	25.62	0.305	5.76	7.95	70.30	2.00	29.70	23,100	17,715	0	0.16	1.05	10495-139	0.99
E115-09 #1	PBS03	10/07/04	11:20	0.457	26.00	0.399	3.75	8.00	63.30	3.10	36.70	49,435	37,451	0	0.16	1.05	None	
E115-09 #1 split	PBS03 split	10/07/04	11:20	0.457								45,690	34,614	0	0.16	1.05	None	
E115-09 #2	PBS04	10/07/04	10:30	0.762	25.05	0.288	3.98	8.02	48.70	6.67	51.30	19,350	14,145	0	0.16	1.05	None	
E115-09 #2 DUP	PBS04 DUP	10/07/04	10:30	0.762								17,820	13,026	0	0.16	1.05	None	
E125 #1	PBS05	10/08/04	12:45	0.274	25.67	0.660	4.00	8.05	44.10	6.12	55.90	272,300	229,983	0	0.77	1.95	13509-001	1.14
E125 #2	PBS06	10/08/04	13:25	0.457	25.70	0.662	3.95	8.04	72.10	1.74	27.90	298,700	200,739	0	0.77	1.95	13509-001	1.14
E140 #1	PBS07	10/08/04	11:45	0.305	25.44	0.184	4.45	7.94	66.20	2.52	33.80	48,700	28,513	0	0.87	1.70	None	
E140 #2	PBS08	10/08/04	10:50	0.610	25.22	0.589	5.00	7.75	63.90	2.88	36.10	40,200	27,610	0	0.87	1.70	None	
E140 #2 split	PBS08 split	10/08/04	10:50	0.610								44,100	30,288	0	0.87	1.70	None	
U106-07 #1	PBS11	10/06/04	12:50	0.152	30.09	0.305	7.54	7.05	64.10	3.94	35.90	6,500	4,738	1	0.08	0.95	None	
U106-07 #2	PBS12	10/06/04	12:00	0.274	30.06	0.299	7.68	7.40	61.10	4.22	38.90	68,300	49,637	1	0.08	0.95	None	
U106-07 #2 DUP	PBS12 DUP	10/06/04	12:00	0.274								86,200	62,645	1	0.08	0.95	None	
E112 #1	PBS09	10/19/04	9:45	0.671	-	-	-	-	77.80	0.81	22.20	63,013	41,489	11	0.00	0.08	12795-001	0.56
E112 #2	PBS10	10/19/04	10:25	0.610	-	-	-	-	31.20	8.23	68.80	16,697	14,246	11	0.00	0.08	12795-001	0.56
E112 #2 split	PBS10 split	10/19/04	10:25	0.610	-	-	-	-				22,240	19,957	11	0.00	0.08	12795-001	0.56
E115 #1	PBS01	10/20/04	14:00	0.914	-	-	-	-	70.70	2.24	29.30	26,030	19,913	5	0.00	0.13	10495-139	0.99
E115 #1 DUP	PBS01 DUP	10/20/04	14:00	0.914	-	-	-	-				38,730	29,628	5	0.00	0.13	10495-139	0.99
E115 #2	PBS02	10/20/04	13:35	0.610	-	-	-	-	72.70	1.44	27.30	54,750	35,626	5	0.00	0.13	10495-139	0.99
E115-09 #1	PBS03	10/20/04	13:00	0.610	-	-	-	-	56.30	3.42	43.70	57,940	42,653	5	0.00	0.13	None	
E115-09 #2	PBS04	10/20/04	12:31	0.610	-	-	-	-	62.70	3.02	37.30	75,923	47,369	5	0.00	0.13	None	
E115-09 #2 split	PBS04 split	10/20/04	12:31	0.610	-	-	-	-				74,930	48,404	5	0.00	0.13	None	
E125 #1	PBS05	10/19/04	11:10	0.914	-	-	-	-	60.50	2.68	39.50	114,500	81,114	11	0.00	0.08	13509-001	1.14
E125 #1 DUP	PBS05 DUP	10/19/04	11:10	0.914	-	-	-	-				145,500	103,075	11	0.00	0.08	13509-001	1.14
E125 #2	PBS06	10/19/04	11:45	0.457	-	-	-	-	86.90	0.78	13.10	8,620	5,042	11	0.00	0.08	13509-001	1.14
E140 #1	PBS07	10/19/04	12:55	0.457	-	-	-	-	52.70	4.37	47.30	20,980	16,178	11	0.00	0.08	None	
E140 #2	PBS08	10/19/04	12:35	0.610	-	-	-	-	66.00	1.69	34.00	31,690	20,149	11	0.00	0.08	None	
U106-07 #1	PBS11	10/19/04	9:10	0.152	-	-	-	-	67.10	2.14	32.90	26,030	15,985	11	0.00	0.08	None	
U106-07 #2	PBS12	10/19/04	8:45	0.305	-	-	-	-	60.20	3.66	39.80	51,720	35,193	11	0.00	0.08	None	

Notes:
1. All #1 stations are upstream of the #2 stations.
2. Storet code shown under name of parameter.

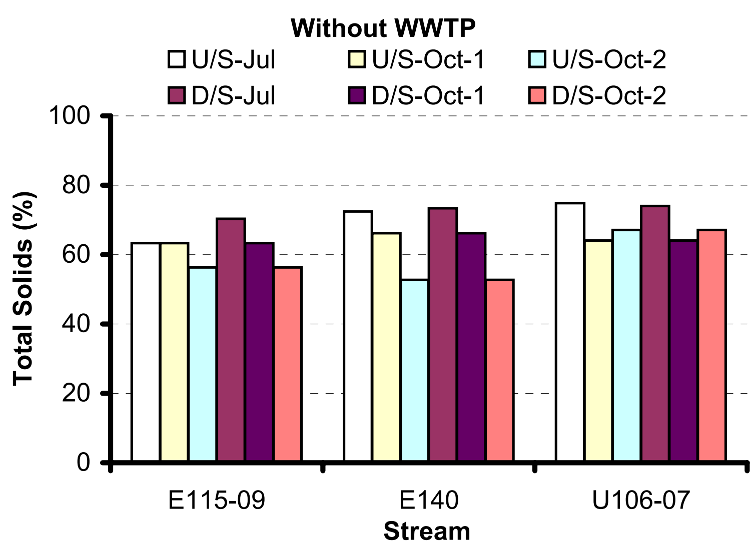
FIGURE 5.3
TOTAL SOLIDS AND VOLATILE SOLIDS DATA FOR STUDYING WWTP EFFECTS ON STREAM SEDIMENTS

Total Solids | **Volatile Solids**





Note:
U/S indicates sample collected in upper bayou
D/S indicates sample collected in lower bayou



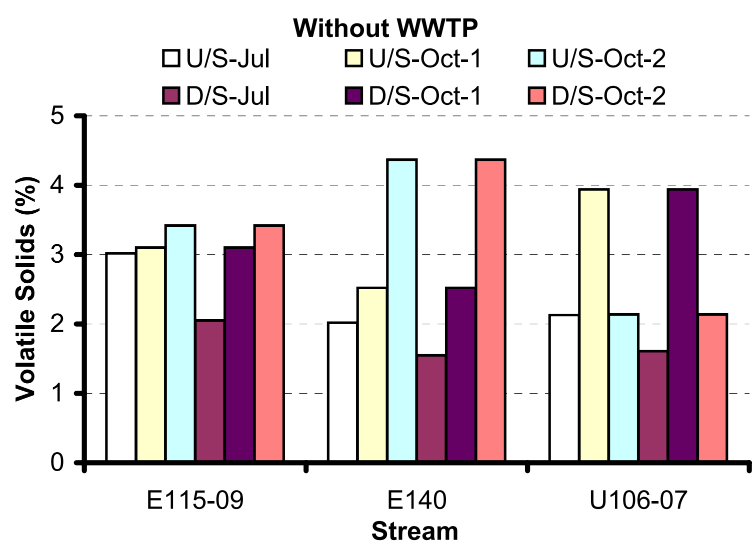
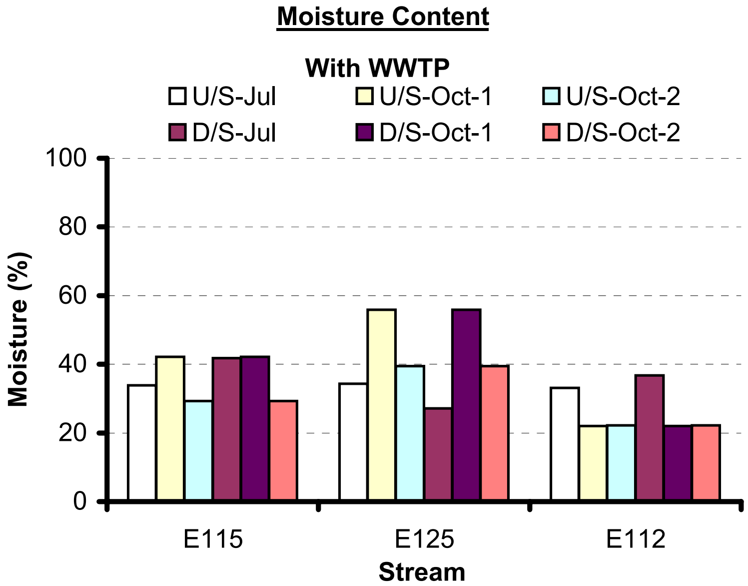
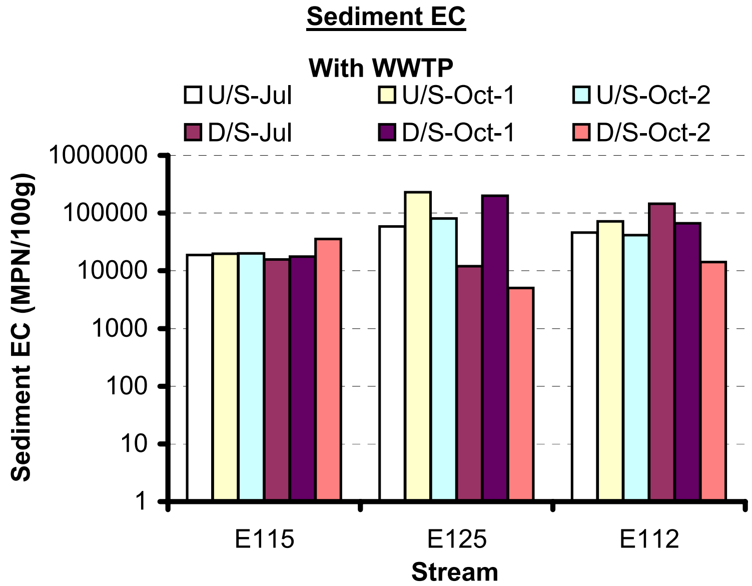
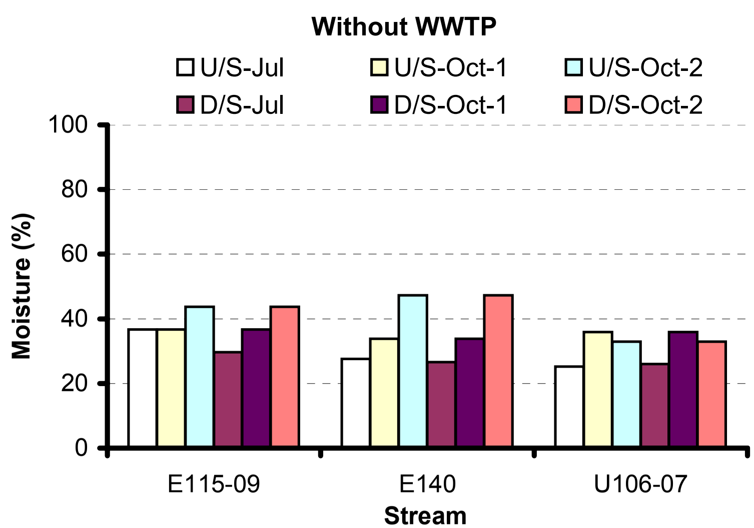


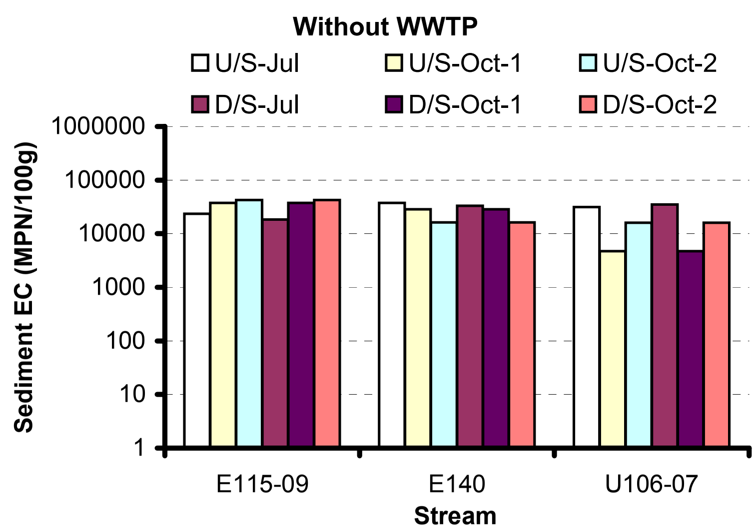
FIGURE 5.4
MOISTURE CONTENT AND EC DATA FOR STUDYING WWTP EFFECTS ON STREAM SEDIMENTS





Note:
U/S indicates sample collected in upper bayou
D/S indicates sample collected in lower bayou





5.3 SETTLING TESTS

To assess the effect of settling on bacteria levels, a set of field and laboratory experiments was conducted. The experiments were designed to track the changes in water bacteria and suspended sediment concentrations over a 24-hr period in quiescent conditions that might exist in pooled areas of streams.

Part of the reason these experiments were conducted was that in the field tests performed in the summer of 2001, very rapid bacterial die-off was observed in control chambers mounted in the bayou. These chambers were constructed with plastic bags that were intended to allow transmission of stream turbulence through the bag walls that would approximate stream conditions while still isolating the sample. However, the relatively high flows and strong currents encountered during the sampling period made it necessary to provide a rigid isolation that limited the turbulence transferred to the bags. It was felt that the results obtained were more representative of quiescent conditions than stream conditions. Also, the results obtained in 2001 showed unexpectedly high die-off rates of bacteria.

This section describes the results of two sets of data, each at two locations, designed to duplicate and confirm the quiescent condition results obtained in 2001. A separate parallel effort to be performed by the City of Houston has been designed to assess the effects of different stream turbulence levels. In short, the tests described here were designed to track high settling rate conditions, focusing on runoff samples that have the highest levels of Total Suspended Solids (TSS). These data are to be used in the model to better represent bacterial die-off and removal by settling.

Runoff samples were collected from two stations, Buffalo Bayou at West Belt and HCFCD drainage channel W153 at Legend Lane, a small tributary. The Buffalo Bayou station had been used in the 2001 sampling and Legend Lane is a small stream in an urban area with no upstream WWTPs. Figure 5.5 shows the locations of the two stations.

Individual samples at the stations were collected for both EC and for TSS, and a larger 2.5-gallon volume of water was also collected. The samples were taken to the PBS&J Environmental Toxicology Laboratory on West Belt, just south of Buffalo Bayou. At the lab, the large containers were first shaken to resuspend particulate matter and a sample withdrawn for EC and TSS analysis.

The containers were then placed in a stable location so that settling could occur. Samples were withdrawn from the large jars at 0.5 hr, 1 hr, 3 hrs and 24 hrs and analyzed for both TSS and EC bacteria. At the end of 24 hrs, the lid was closed and the containers shaken followed by collecting the final samples.

The sampling results from the laboratory are shown in Table 5.3 and while the field parameters are shown in Table 5.4. Figure 5.6 shows the TSS results for the two stations, with both sampling events shown at each station. Figure 5.7 shows the EC results. The EC results on August 28, 2004, for both stations were done in duplicate, with one sample taken 1 inch below the surface of the water and the other 3 inches above the bottom. The samples at lower depth had higher EC concentrations, reflecting the settling process. The TSS plots show steady declines indicating reasonable settling progress at both stations. Note that the TSS values were much higher in the Buffalo Bayou samples than in the Legend Lane tributary samples.

The TSS plots include a Field result when the sample was collected. This is a separate sample collected at the same time and place, and is sometimes different from the initial jar sample. At the end of the 24-hr period, an agitated bottle sample result, and a Theoretical agitated result are shown in addition to the final quiescent sample. The Theoretical value reflects the sample volume and TSS concentrations removed from the 2.5-gallon jar by sampling during the period. This is

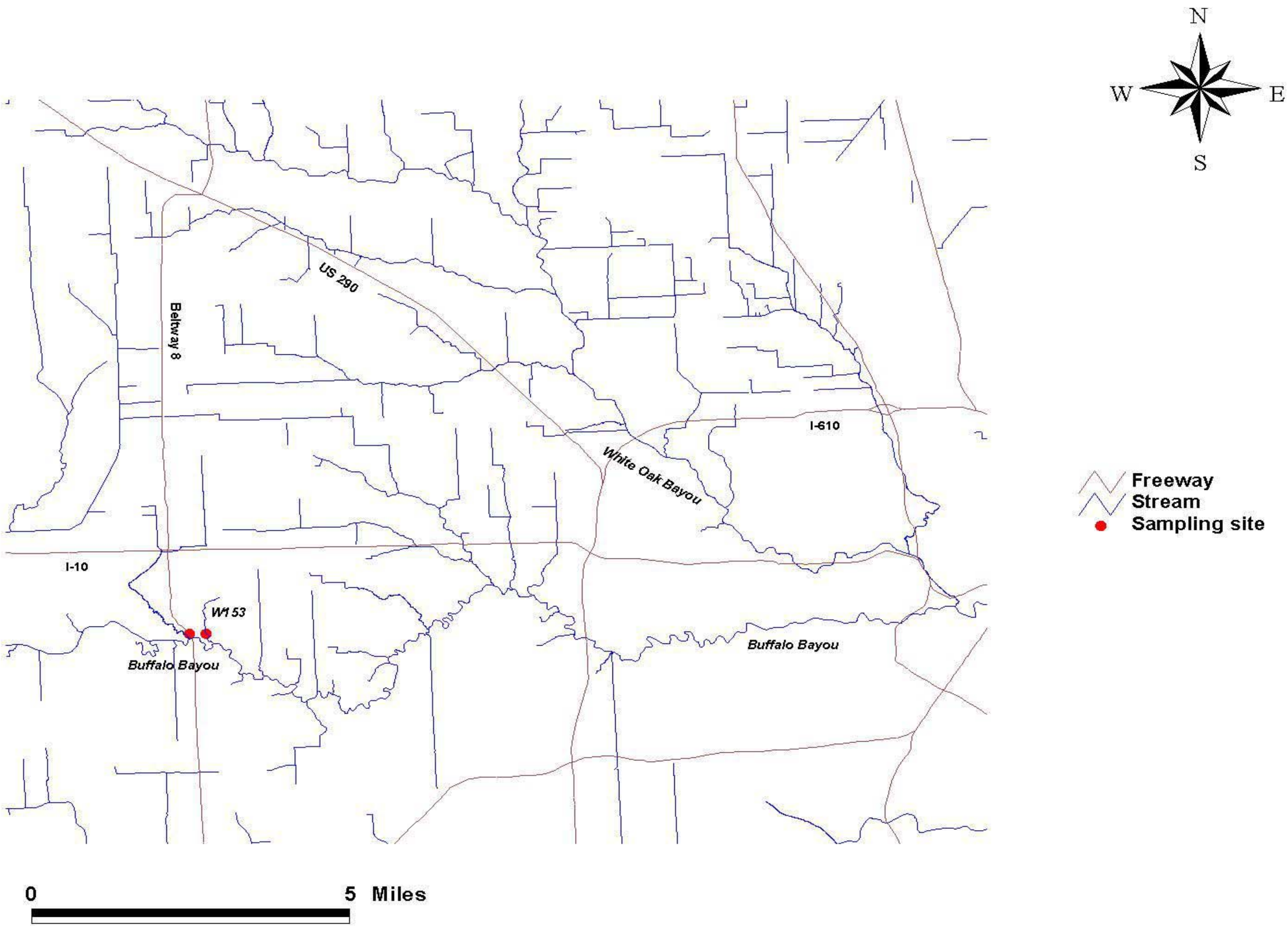


Figure 5.5 Locations of Sampling Sites for Settling Tests

TABLE 5.3
FIELD DATA OF SETTLING TEST SAMPLES

Station	Stationid	Date	Time	Depth	Temperature 00010 (ºC)	Conductivity 00094 (µmhos/cm)	DO 00300 (mg/L)	pH 00400	TDS 70300 (mg/L)	TSS 00530 (mg/L)	EC 31699 (MPN/dL)	Days from last rain 72053	1-d prior rain 82553 (in)	7-d prior rain 82554 (in)
Buffalo Bay	11360	07/22/04	13:40	0.46	28.38	0.789	8.12	7.74	34.3	343.0	9,335	5	0.31	0.94
Buffalo Bay	11360 DUP	07/22/04	13:40	0.46							9,065			
W153/Lege	PBW01	07/22/04	14:45	0.39	27.87	0.496	6.33	8.07	78.8	78.8	36,330	5	0.31	0.94
Buffalo Bay	11360	08/28/04	17:00	0.46	25.90	1.681	6.05	7.15		98.0	32,550	4	0.98	1.14
W153/Lege	PBW01	08/28/04	16:20	0.46	24.60	1.845	6.60	8.30		32.0	45,645	4	0.98	1.14

Note:
Storet code shown under name of parameter.

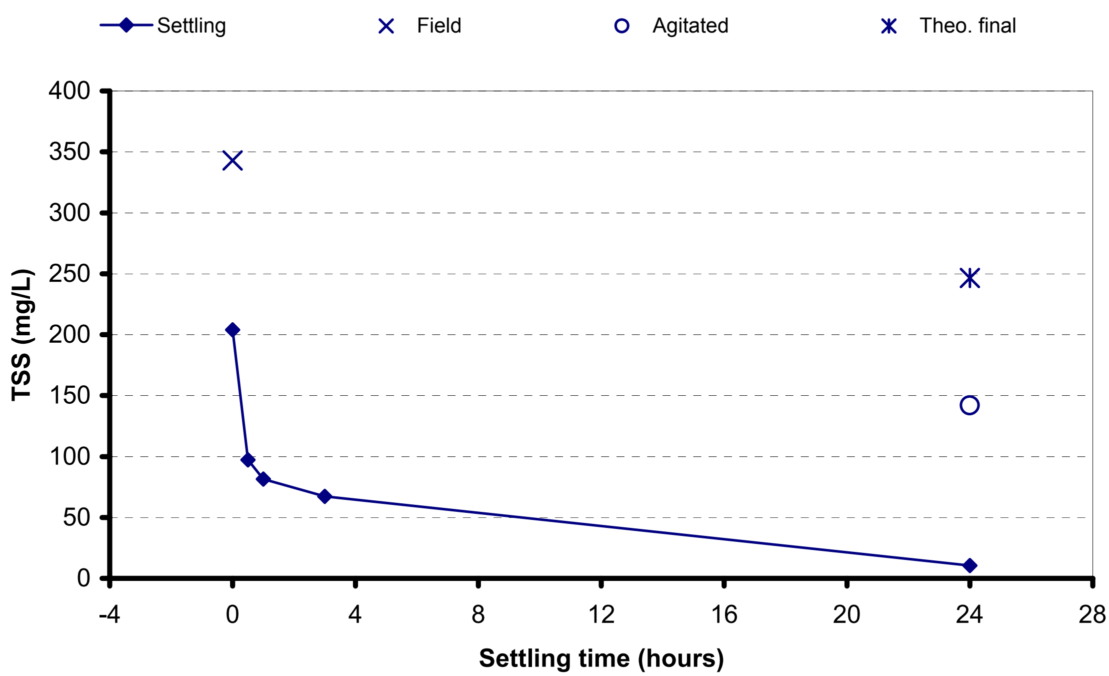
TABLE 5.4
SETTLING TEST DATA

Sample Location	Station Code	Date	Collected Time	Incubation Start Time	Settling Time (hours)	Sample Depth (1" from top or 3" from bottom)	Reported EC 31699 (MPN/dL)	TSS 00530 (mg/L)
Beltway 8	11360	07/22/04	13:40	17:30	0.0	3	38,800	204.0
Beltway 8	11360	07/22/04	13:40	18:00	0.5	3	15,920	97.2
Beltway 8	11360	07/22/04	13:40	18:45	1.0	3	11,000	81.6
Beltway 8	11360	07/22/04	13:40	20:00	3.0	3	15,695	67.2
Beltway 8	11360	07/22/04	13:40	17:00	24.0	3	11,995	10.4
Beltway 8- Agitated	11360	07/22/04	13:40	17:00	24.0	3	38,035	142.0
Legend Lane	PBW01	07/22/04	14:45	17:30	0.0	3	16,050	84.4
Legend Lane	PBW01	07/22/04	14:45	18:00	0.5	3	34,545	48.4
Legend Lane	PBW01	07/22/04	14:45	18:45	1.0	3	41,125	35.2
Legend Lane	PBW01	07/22/04	14:45	20:00	3.0	3	112,475	24.8
Legend Lane	PBW01	07/22/04	14:45	17:00	24.0	3	49,920	6.0
Legend Lane- Agitated	PBW01	07/22/04	14:45	17:00	24.0	3	136,850	33.2
Legend Lane- Agitated DUP	PBW01	07/22/04	14:45	17:00	24.0	3	129,973	
Beltway 8	11360	08/28/04	17:00	18:35	0.0	1	46,390	253.0
Beltway 8	11360	08/28/04	17:00	19:30	0.5	1	46,110	121.0
Beltway 8	11360	08/28/04	17:00	20:05	1.0	1	86,860	109.0
Beltway 8	11360	08/28/04	17:00	21:35	3.0	1	155,310	80.8
Beltway 8	11360	08/28/04	17:00	18:50	24.0	1	32,815	7.5
Beltway 8- Agitated	11360	08/28/04	17:00	19:20	24.0	1	61,310	105.0
Legend Lane	PBW01	08/28/04	16:20	18:35	0.0	1	34,745	54.0
Legend Lane	PBW01	08/28/04	16:20	19:30	0.5	1	35,510	29.6
Legend Lane	PBW01	08/28/04	16:20	20:05	1.0	1	28,215	26.0
Legend Lane	PBW01	08/28/04	16:20	21:45	3.0	1	26,205	22.4
Legend Lane	PBW01	08/28/04	16:20	19:10	24.0	1	14,805	19.6
Legend Lane- Agitated	PBW01	08/28/04	16:20	19:20	24.0	1	25,865	70.4
Beltway 8	11360	08/28/04	17:00	19:30	0.5	3	81,640	
Beltway 8	11360	08/28/04	17:00	20:05	1.0	3	92,080	
Beltway 8	11360	08/28/04	17:00	21:35	3.0	3	241,920	
Beltway 8	11360	08/28/04	17:00	18:50	24.0	3	38,730	
Legend Lane	PBW01	08/28/04	16:20	19:30	0.5	3	27,230	
Legend Lane	PBW01	08/28/04	16:20	20:05	1.0	3	30,760	
Legend Lane	PBW01	08/28/04	16:20	21:45	3.0	3	30,760	
Legend Lane	PBW01	08/28/04	16:20	19:10	24.0	3	14,830	

Note:
Storet code shown under name of parameter.

FIGURE 5.6
TSS SETTLING TEST RESULTS

Station 11360 - Buffalo Bayou at West Belt, 7/22/04 results



Station 11360 - Buffalo Bayou at West Belt, 8/28/04 results

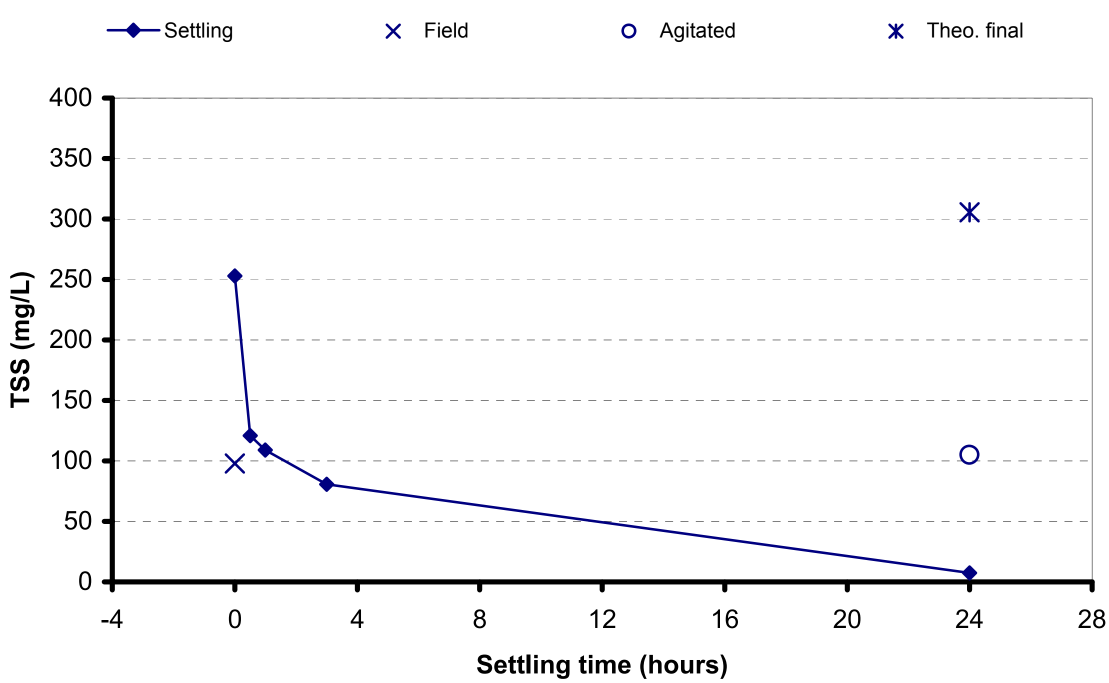
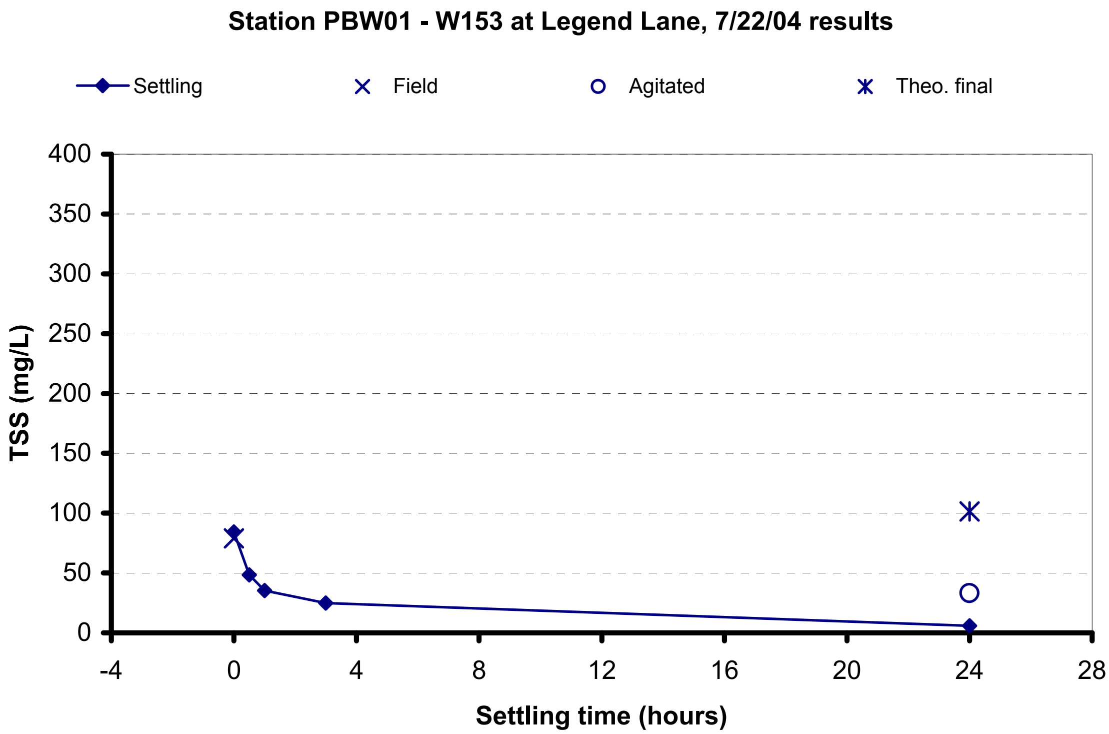


FIGURE 5.6 (CONTINUED)
TSS SETTLING TEST RESULTS



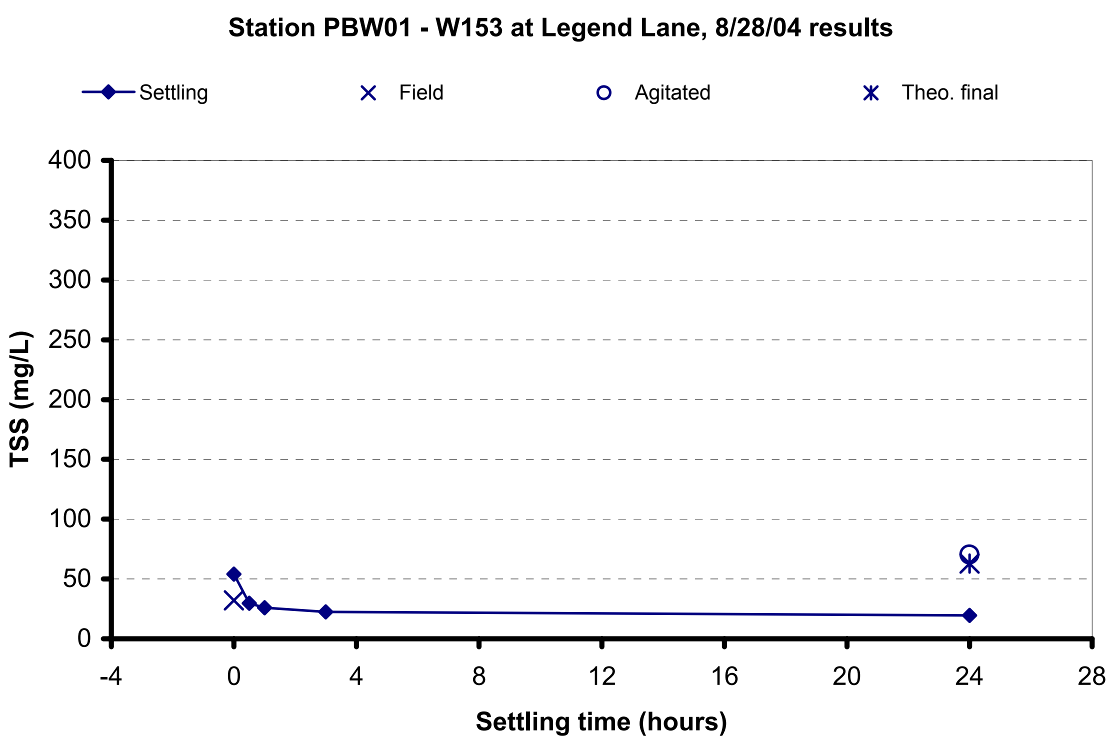
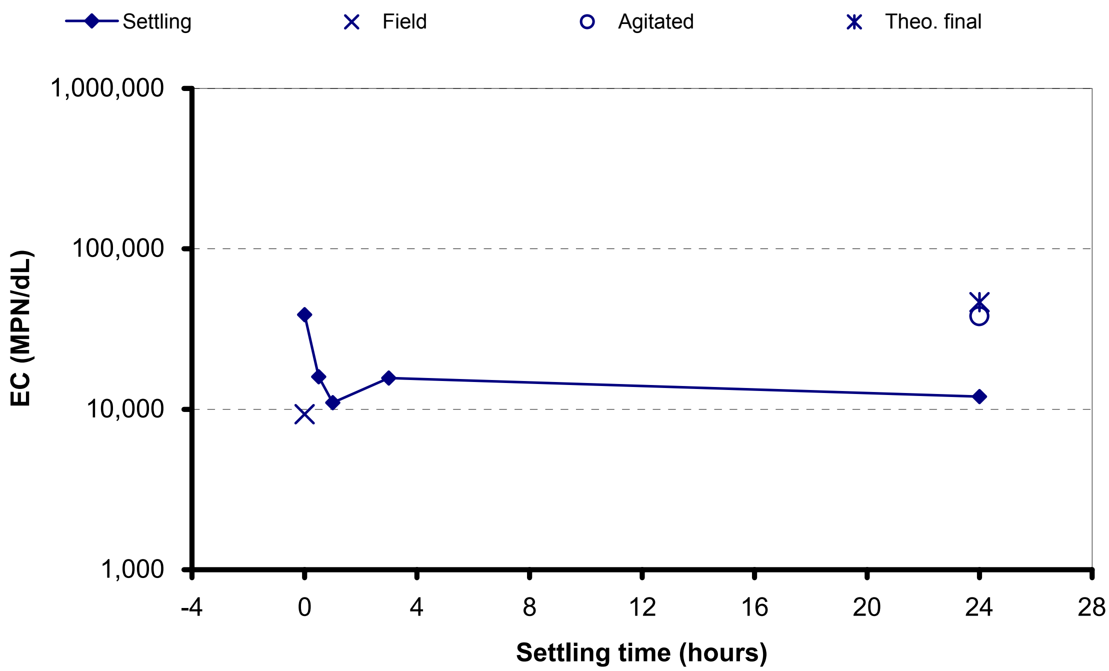


FIGURE 5.7
EC SETTLING TEST RESULTS

Station 11360 - Buffalo Bayou at West Belt, 7/22/04 results



Station 11360 - Buffalo Bayou at West Belt, 8/28/04 results

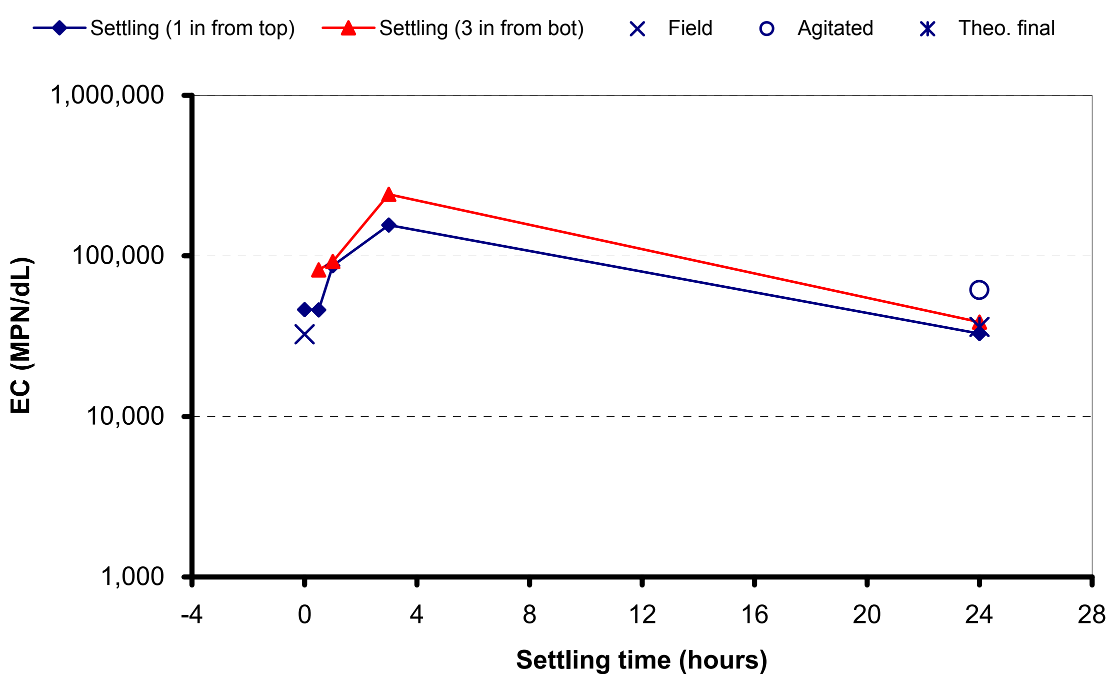
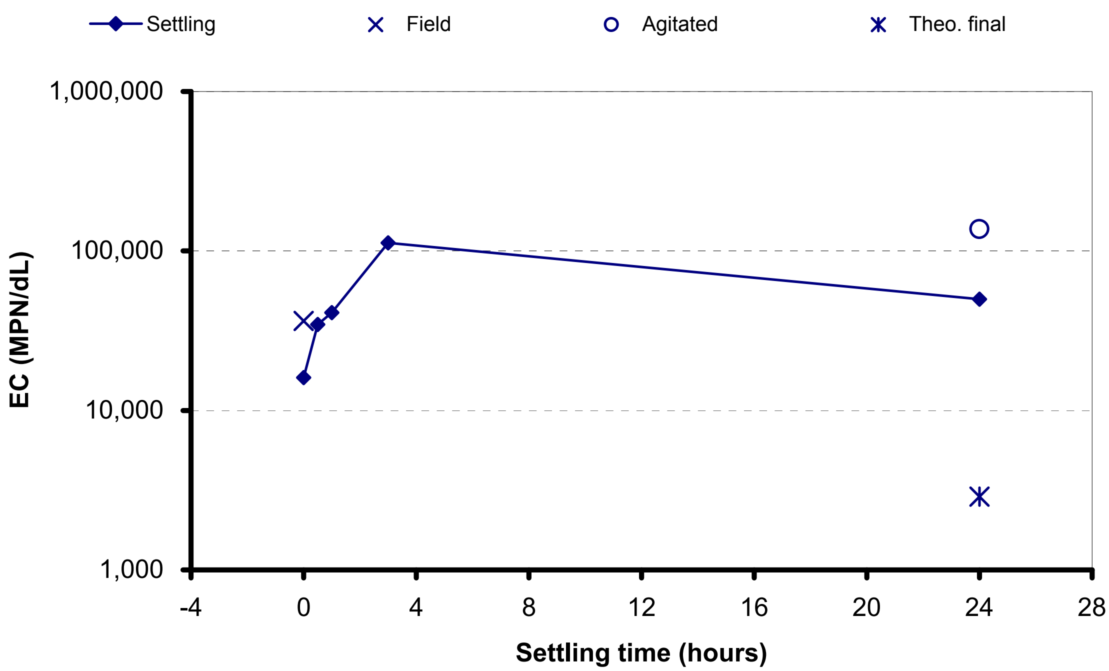
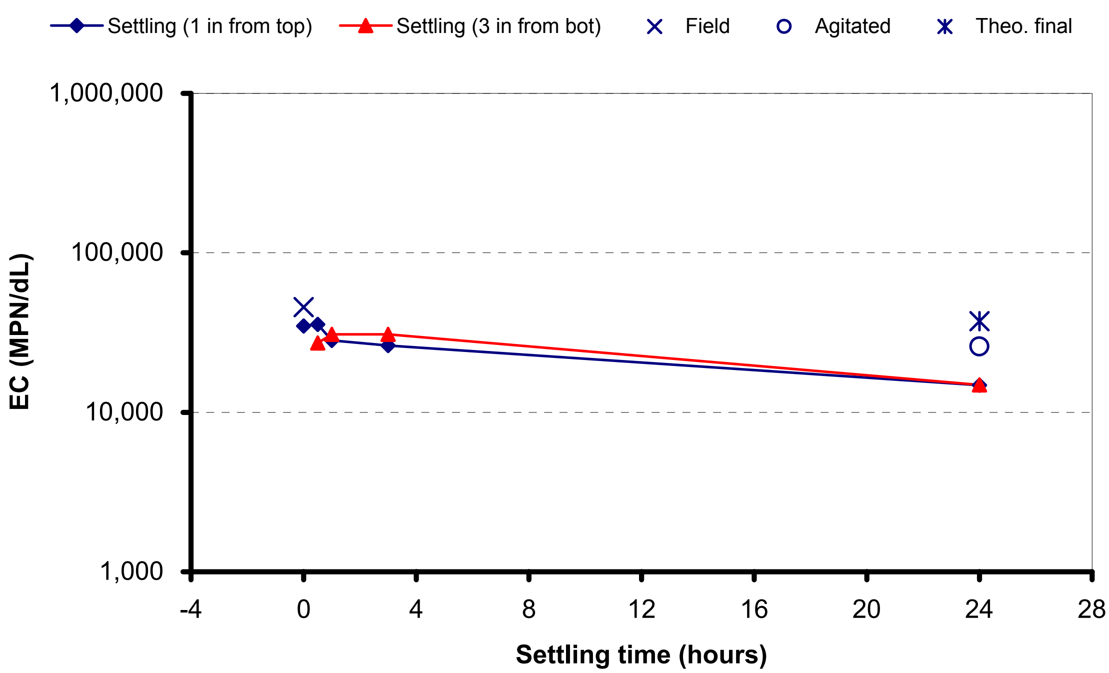


FIGURE 5.7 (CONTINUED)
EC SETTLING TEST RESULTS

Station PBW01 - W153 at Legend Lane, 7/22/04 results



Station PBW01 - W153 at Legend Lane, 8/28/04 results



calculated by taking the initial mass of TSS in the jar at time zero, subtracting the mass of TSS removed on each sampling, and calculating a final value with the remaining TSS and volume of water at the end of the period. It is always higher than the initial TSS observation. In three of the four experiments the measured sample taken from the agitated jar was lower in concentration than the theoretical value, probably reflecting difficulty in getting sufficient agitation in the large jar. The test where there was good agreement was on the sample with the lowest TSS level, Legend Lane on August 28, 2004.

It was expected that the EC values would exhibit a similar decline to the TSS, but that did not always prove to be the case with these stormwater samples. Instead, at each station one of the sample sets exhibited significant increases in the first 3 hrs before showing more rapid reduction. Even the sample with the largest die-off (BB on July 22, 2004), the rate was not as high as the highest value of 3/day observed during the 2001 work. However, all of the samples showed a decline in concentration between the 3-hr and 24-hr observations. It appears that the settling removal of TSS, with the biggest reductions in the first 30 minutes, is dominated by larger particles that may not have the same bacterial association as the smaller, slower settling fraction of the suspended solids. This suggests that the bacteria may be preferentially associated with the fine and slower settling solids.

The overall average first-order decay rate for the 24-hr period was 0.31/day, much lower than used in the modeling up to now that was based on 2001 field measurements. The rates observed in 2001 averaged between 1.0 and 2.0/day, and these rates were used in the bulk of the model segments. However, if the rate for the 21-hr period from hour 3 to the end of the test is considered, the average die-off rate under quiescent conditions is 0.975/day, closer to what was observed during 2001.

These rates are lower than used before, but still higher than would be expected if settling were not playing a role in the reduction of bacteria concentrations. As noted earlier, additional tests of the bacteria reduction rate are planned using chambers with two different levels of mixing to represent stream turbulence. These tests are to be conducted by the City of Houston, Health and Human Services Laboratory with support from the TCEQ's Clean Rivers Program (H-GAC, 2004). These should provide a better indication of the die-off rate where settling is not playing a role.

5.4 DISCUSSION

The basic message from this assessment of sediment contributions is that indicator bacteria and sediment are closely intertwined. Soils and stream sediment provide an ideal habitat for indicator bacteria to survive and grow, and indicator bacteria are a component of solids suspended in the water and sediments in the streambed. With soils and sediments supporting a rich culture of bacteria, many of which are species that make up the indicator groups, it is not surprising that high concentrations of indicator bacteria are found in water samples collected during runoff events.

Settling of sediments and organic material that includes bacteria is an important part of the hydrology in the Houston area. The studies above provide an indication that bacteria are not strongly associated with the larger sediment that settles rapidly but rather with smaller particles that settle more slowly. The data also suggest that the rate of bacterial die-off may be slower than indicated in earlier tests.

CHAPTER 6

LEVELS OF EC IN ADDICKS AND BARKER RESERVOIRS

The operation of the Addicks and Barker Reservoirs in the upper watershed of Buffalo Bayou is thought to have an impact on the water quality of Buffalo Bayou. In the late 1970's, the United States Geological Survey conducted an in-depth study on these reservoirs (USGS, 1987). The results of this study suggested that the reservoirs settle out bacteria and sediment when pools are present, thus improving water quality. There have been, however, many changes in the watersheds since the USGS study was conducted. Since the early 1980's, Houston has experienced tremendous growth, especially in the outlying suburbs. While the surrounding area of the reservoirs was generally cropland during the 1970's (US EPA, 2001), the area is now heavily populated and is developed for primarily commercial and residential land uses.

These changes in the land use have certainly impacted the quality of the water entering the reservoirs. How these changes have affected the ability of the reservoir to attenuate bacteria and sediment is not known. The following sections are intended to provide insight into the magnitude of the bacterial indicator levels from the Addicks and Barker reservoirs and loads released from the reservoirs.

6.1. RESERVOIR OPERATION

The Addicks and Barker Reservoirs were completed in 1945 as a flood control project to protect downtown Houston (Figure 6.1). The reservoirs are generally operated as dry reservoirs, meaning that they hold no water. Under periods of heavy rain, however, the gates of the

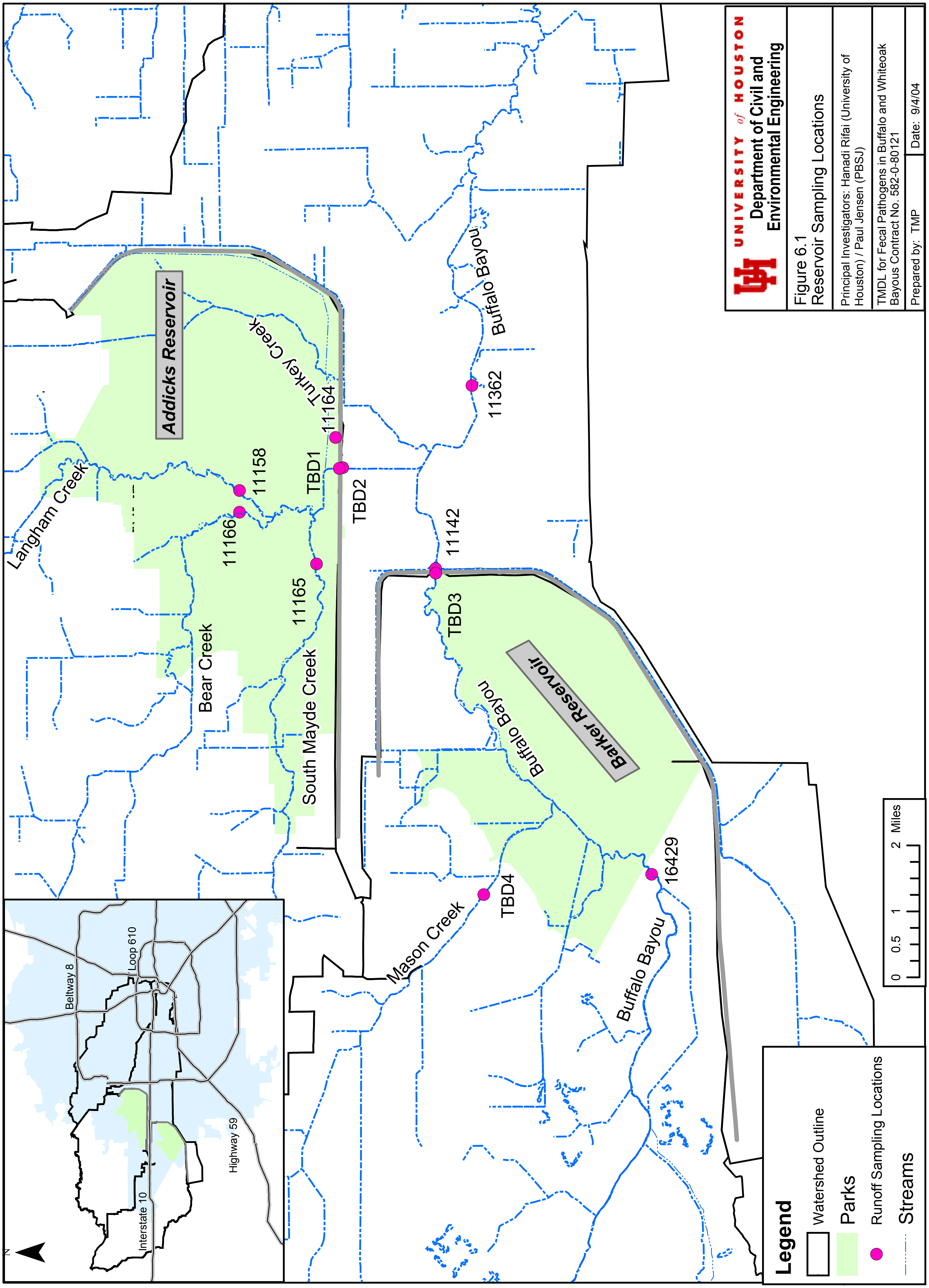


Figure 6.1
Reservoir Sampling Locations

reservoirs may close and store water to prevent downstream flooding. The maximum joint capacity of the two reservoirs, 409,853 acre-ft, has never been reached. Based upon estimates from the Army Corps of Engineers, the rainfall event that occurred in March 1992 resulted in the largest reservoir pools, with storage within Addicks Reservoir at 57,956 acre-ft and 66,910 acre-ft at Barker Reservoir. In July 2004, the reservoirs were slightly smaller than the 10th largest pool size, with a maximum storage at 29,185 acre-ft for Addicks Reservoir and 28,798 acre-ft for Barker.

As the sole intent of the reservoirs is to protect downtown Houston from flooding, the reservoirs are closed when there appears to be an imminent threat downstream. The criterion that have been set by the Army Corps of Engineers is basically to prevent flows at Piney Point from exceeding 2000 cfs. This criterion is not rigorous; rather it is based upon professional judgment. As a rule of thumb, it appears that the reservoirs are generally closed when approximately 2 or more inches of rain are predicted for the reservoir watershed. Another situation when the reservoir gates are closed occurs when the reservoir is releasing previously retained water and a storm is predicted. In that case, the reservoirs would be closed if around ½ inch of rain is predicted.

Since January 1, 2004, the reservoirs have been closed for a total of 19 days in Addicks and 20 days in Barker (approximately 5% of the time). During the days when the reservoirs are closed, they accumulate water and a pool is formed. The relationship between reservoir discharges and the amount of storage in the reservoir pool can be observed in Figures 6.2 and 6.3. Figure 6.2 presents the discharge of water from the reservoirs; when the discharge is zero, the reservoirs are closed. Discharge increases after a rainfall event and also after the release of the stored water. Figure 6.3, on the other hand, presents the amount of water stored in the

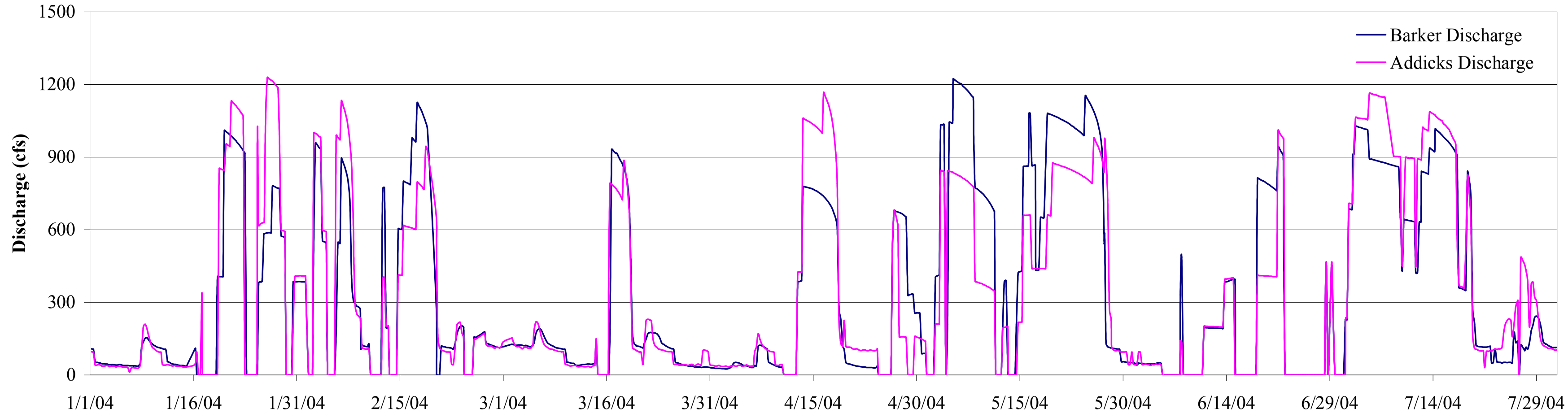


Figure 6.2 Reservoir Discharge

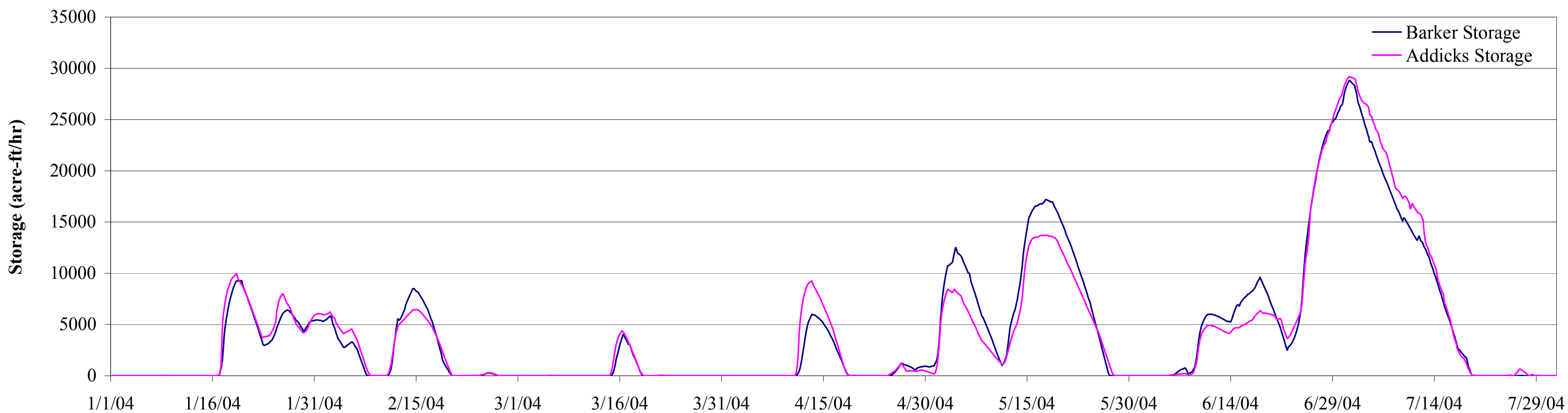


Figure 6.3 Reservoir Storage

reservoir when it is closed. There were approximately eight water storage events during 2004, with the event in July being the largest.

6.2. DRY WEATHER RESERVOIR SAMPLING

During dry weather, the reservoirs are essentially non-functional, meaning that streams flowing into the reservoir flow through the dam and out the discharge structure un-impeded. The dry weather sampling is therefore intended to provide a baseline with which to compare to the wet weather sampling.

Dry weather samples were collected at streams entering the reservoir, as well as the reservoir discharges and a point downstream of the discharges, Dairy Ashford. Procedures and methods specified in the QAPP were followed. A total of three dry weather samples have been collected on the following dates: July 24, 2004, August 9, 2004 and August 27, 2004. The reservoirs were sampled following three or more days of dry weather. Generally, one sampling team sampled each of the locations shown in Figure 6.1 (excluding reservoir pools). Sampling generally commenced in the morning, with the first samples collected at Buffalo Bayou at Dairy Ashford, followed by samples being collected in Barker then Addicks Reservoirs. If two teams were conducting sampling, then one team collected samples at Dairy Ashford and within the Barker Reservoir and the other team collected samples within the Addicks Reservoir.

Table 6.1 presents the results from the dry weather sampling and summary statistics are provided in Tables 6.2 and 6.3. The dry weather results are quite variable, as evidenced by the high standard deviations in Table 6.2. EC results range from 1 MPN/dL (found at Station 16428, BB at Westheimer) to 27,685 MPN/dL (found at TBD2, Addicks Discharge), with a geometric mean of 366 MPN/dL. Exactly 72% of the EC samples exceeded the long-term geometric mean

Table 6.1. Dry Weather Reservoir Water Quality Results[a]

Date	Station[e]	Total Coliform (MPN/dL)	*E. coli* (MPN/dL)	TSS (mg/L)	TDS (mg/L)	TOC (mg/L)	DOC[b] (mg/L)	Temp[c] (C)	Conductivity (μs/cm)	DO (mg/L)	pH	Turbidity (NTU)	Phosphorous (mg/L)
7/24/2004	11142	137819	133	223	406	10.0	-[b]	31.1	750	6.7	7.8	-[c]	2.2
7/24/2004	11158	>241920	18135	50	22	10.5	-[b]	29.4	301	3.4	7.2	-[c]	0.1
7/24/2004	11164	>241920	5517	66	167	11.3	8.3	30.9	156	6.4	7.1	-[c]	0.5
7/24/2004	11165	120974	437	73	444	9.4	8.3	29.3	767	4.9	7.5	-[c]	4.8
7/24/2004	11166	48840	121	22	511	8.5	7.7	29.9	860	4.9	7.6	-[c]	7.0
7/24/2004	11362	>241920	14915	150	194	13.0	8.4	28.8	374	5.9	7.3	-[c]	1.8
7/24/2004	16428	8065	10	67	340	10.2	-[b]		585	5.2	7.8	-[c]	2.6
7/24/2004	TBD 2	>241920	27685	158	156	13.3	-[b]	29.2	243	6.9	7.3	-[c]	3.0
8/9/2004	11142	32333	96	104	443	11.3	10.7	28.1	329	1.2	7.2	65.3	0.6
8/9/2004	11158	24850	176	28	510	11.7	10.9	30.3	851	2.7	8.3	39.4	5.2
8/9/2004	11164	21480	6	9	200	11.8	11.7	-[c]	-[c]	-[c]	-[c]	-[c]	2.3
8/9/2004	11165	23120	207	9	449	9.9	9.7	-[c]	-[c]	-[c]	-[c]	-[c]	4.4
8/9/2004	11166	19485	507	11	459	9.4	9.0	29.1	747	3.0	7.8	16.6	3.3
8/9/2004	11362	27175	551	45	513	10.1	9.7	29.0	772	5.4	8.2	28.6	5.0
8/9/2004	16428	5684	1	47	430	12.7	12.1	29.9	646	6.3	8.7	103.7	1.7
8/9/2004	TBD 2	28445	105	22	469	10.7	10.4	-[c]	-[c]	-[c]	-[c]	-[c]	3.7
8/27/2004	11142	152829	526	112	319	10.3	8.93	29.1	524	4.5	7.7	521	3.9
8/27/2004	11362	99420	592	71	357	9.74	8.51	28.7	626	3.5	7.6	780.2	4.0
8/27/2004	11164	46035	101	47	240	13.6	10.2	26.9	279	1.6	7.2	159.0	0.3
8/27/2004	11165	54750	195	9	366	9.27	8.48	28.0	632	3.4	7.5	19.3	4.6
8/27/2004	11158	93132	916	21	403	11	9.42	30.0	653	2.4	7.4	55.3	4.5
8/27/2004	16428	105013	371	109	356	10.5	9.33	30.6	635	2.4	7.6	134.1	5.1
8/27/2004	TBD 2	114003	712	33	379	10.4	9.19	28.3	609	4.7	7.7	50.8	3.9
8/27/2004	11166	45530	1932	9	405	8.82	7.79	28.8	712	3.0	7.5	23.7	1.2
8/27/2004	TBD4	125148	1883	128	404	10.4	8.71	27.9	595	2.9	7.6	270.4	4.9

[a] Duplicates were averaged

[b] DOC could not be obtained for all samples due to filtration difficulties

[c] Probe parameters not available on all samples due to malfunctioning probe or due to fact that turbidity is not available on all probe

[d] Summary statistics treated concentrations greater than detection limit as the detection limit

[e] Stations correspond to the following locations:

11142	Barker Discharge	11362	Dairy Ashford
11158	Langham Creek	16428	BB @ Westheimer
11164	Turkey Creek	TBD 2	Addicks Discharge
11165	S. Mayde Creek	TBD4	Mason Creek
11166	Bear Creek		

Table 6.2 Summary Statistics for Dry Weather Reservoir Sampling

	Average	Geometric Mean	Standard Deviation	Minimum	Maximum
Total Coliform (MPN/dL)	92072	59002	79492	5684	>241920
E. coli (MPN/dL)	3033	363	6857	1	27685
TSS (mg/L)	64.9	42.9	56.0	9.0	223.0
TDS (mg/L)	357.7	315.5	127.2	22.0	513.0
TOC (mg/L)	10.7	10.6	1.4	8.5	13.6
DOC (mg/L)	9.4	9.3	1.2	7.7	12.1
Temp (^{o}C)	29.2	29.2	1.1	26.9	31.1
Conductivity (μs/cm)	574.8	528.2	205.4	156.0	860.0
DO (mg/L)	4.1	3.8	1.7	1.2	6.9
pH	7.6	7.6	0.4	7.1	8.7
Turbidity (NTU)	161.9	79.2	224.2	16.6	780.2
Phosphorous (mg/L)	3.2	2.4	1.8	0.1	7.0

Note: Samples greater than detection limit were treated as detection limit standard of 126 MPN/dL, while 56% of the samples exceeded the single sample standard of 394 MPN/dL. The maximum concentrations of most parameters were found during the first sampling event in July. This bias towards high values may indicate that the first event does not completely represent ambient conditions, although the first event is not statistically different in terms of EC concentrations from the second or third events (Kruskal-Wallis test, $p = 0.057$). One possible explanation for the differences observed between the first event and the remaining events is the fact that the reservoir pools had just been emptied on July 20, 2004 after an extended water storage period. The water quality may have still been influenced, perhaps by sediment that had settled out of water column during the detection period. This explanation is supported by the fact that higher TSS concentrations were noted in the first dry weather sampling event when compared with the other two events. Additionally, there were only two gates open for the Addicks Reservoir between 7/19/2004 and 7/25/2004, which caused some impoundment of water even though there were no rainfall events. This caused the flow from the Addicks Reservoir to be higher than normal and affected the water quality of Addicks Discharge.

The EC concentrations were examined for each station as well as TSS, TDS, TOC, DOC and orthophosphorous, as shown in Table 6.3. Station 11362 (Dairy Ashford) had the highest geometric mean EC concentration, while station 16428 (Buffalo Bayou at Westheimer) had the lowest concentrations. Barker Reservoir sites generally had lower EC concentrations than their counterparts in Addicks Reservoir, as exhibited by a geometric mean of 94 MPN/dL in Barker and 509 MPN/dL in Addicks. Station 11142 (Barker Discharge) had the highest average TSS concentrations, while station 11166 (Bear Creek) had the lowest. In general, Barker Reservoir stations had higher concentrations of TSS than their counterparts in Addicks Reservoir. TOC and DOC exhibited similar trends, with higher averages being found in Barker Reservoir.

Table 6.3 Statistics for Individual Stations - Dry Weather Sampling

Station	E. coli (MPN/dL)					TSS (mg/L)					TDS (mg/L)				
	Avg	Geometric Mean	Std Dev	Min	Max	Avg	Geometric Mean	Std Dev	Min	Max	Avg	Geometric Mean	Std Dev	Min	Max
11142 - Barker Discharge	252	189	238	96	526	146.2	137.2	66.7	104	223	389.3	385.7	63.7	319	443
11158 - Langham Crk	6409	1430	10162	176	18135	33.0	30.9	15.1	21	50	311.7	165.4	256.5	22	510
11164 - Turkey Crk	1875	146	3155	6	5517	40.7	30.3	29.0	9	66	202.3	200.1	36.6	167	240
11165 - S. Mayde Crk	280	260	136	195	437	30.3	18.1	37.0	9	73	419.7	417.9	46.5	366	449
11166 - Bear Crk	853	491	954	121	1932	14.0	13.0	7.0	9	22	458.3	456.3	53.0	405	511
11362 - Dairy Ashford	5353	1695	8281	551	14915	88.7	78.3	54.7	45	150	354.7	328.7	159.5	194	513
16428 - BB at Westheimer	128	17	211	1	371	74.3	70.0	31.6	47	109	375.3	373.4	48.0	340	430
TBD 2 - Addicks Discharge	9501	1276	15751	105	27685	71.0	48.6	75.5	22	158	334.7	302.7	161.1	156	469
TBD4[a] - Mason Crk	-	-	-	-	-	-	-				-	-	-	-	
Barker Reservoir Sites[b]	432	94	669	1	1883	112.8	101.8	56.1	47	223	385.4	382.9	47.3	319	443
Addicks Reservoir Sites[c]	509	509	8092	6	27685	37.8	25.4	39.3	9	158	345.3	285.9	150.3	22	511

Station	TOC (mg/L)					DOC (mg/L)					Phosphorous (mg/L)				
	Avg	Geometric Mean	Std Dev	Min	Max	Avg	Geometric Mean	Std Dev	Min	Max	Avg	Geometric Mean	Std Dev	Min	Max
11142 - Barker Discharge	10.53	10.52	0.68	9.99	11.30	9.82	9.78	1.25	8.93	10.70	2.24	1.75	1.63	0.62	3.88
11158 - Langham Crk	11.07	11.06	0.60	10.50	11.70	10.16	10.13	1.05	9.42	10.90	3.24	1.36	2.73	0.11	5.16
11164 - Turkey Crk	12.23	12.19	1.21	11.30	13.60	10.08	9.98	1.69	8.33	11.70	1.06	0.72	1.11	0.30	2.33
11165 - S. Mayde Crk	9.52	9.51	0.30	9.27	9.85	8.84	8.81	0.78	8.30	9.73	4.62	4.61	0.23	4.39	4.84
11166 - Bear Crk	8.93	8.92	0.46	8.53	9.43	8.16	8.14	0.71	7.70	8.98	3.84	3.04	2.90	1.22	6.96
11362 - Dairy Ashford	10.95	10.85	1.79	9.74	13.00	8.88	8.86	0.73	8.42	9.72	3.60	3.31	1.62	1.82	4.97
16428 - BB at Westheimer	11.13	11.08	1.37	10.20	12.70	10.72	10.63	1.96	9.33	12.10	3.12	2.80	1.79	1.66	5.12
TBD 2 - Addicks Discharge	11.47	11.40	1.59	10.40	13.30	9.80	9.78	0.86	9.19	10.40	3.53	3.50	0.47	3.00	3.90
TBD4[a] - Mason Crk	-	-				-	-	-	-		-	-	-	-	
Barker Reservoir Sites[b]	10.77	10.74	0.95	9.99	12.70	9.95	9.88	1.43	8.71	12.10	3.00	2.48	1.70	0.62	3.25
Addicks Reservoir Sites[c]	10.64	10.54	1.52	8.53	13.60	9.32	9.24	1.23	7.70	11.70	3.25	2.17	2.00	0.11	6.96

[a] Only one sampling event was conducted at this site

[b] Barker Reservoir sites include 11142, 16428, TBD4

[c] Addicks Reservoir sites include 11158, 11164, 11165, 11166, TBD2

Phosphorous values exhibited a large range of concentrations, with higher concentrations generally observed at Barker Reservoir sites.

6.3 WET WEATHER RESERVOIR SAMPLING

Wet weather samples were collected at the same locations as dry weather samples, with additional samples collected in Addicks and Barker Pools when the reservoir gates were closed. Three wet weather events were conducted on the following dates: July 25, 2004, August 19, 2004, and August 28, 2004. Wet weather sampling events were conducted only when there had been at least three days of dry weather prior to the storm being sampled. Procedures and methods specified in the QAPP were followed.

Samples were collected by two teams; one team covered Barker Reservoir and the other team covered Addicks Reservoir. Dairy Ashford was sampled by the Barker team. When the chance of rain was high (generally 30% or greater), the runoff teams were notified that mobilization could be possible and storms in the Houston area were tracked closely. Mobilization occurred when a storm was moving towards the reservoir watershed and was at least two hours away. To optimize the time it took to mobilize, the sampling equipment for runoff was prepared prior to mobilization. This allowed the teams to arrive at the field office and load the sampling vehicles very quickly.

The teams began sampling as soon as they arrived in the area. During two runoff events, the teams arrived prior to or just as the rain was starting, but for the August 28 event, traffic prohibited the teams from arriving prior to the rainfall.

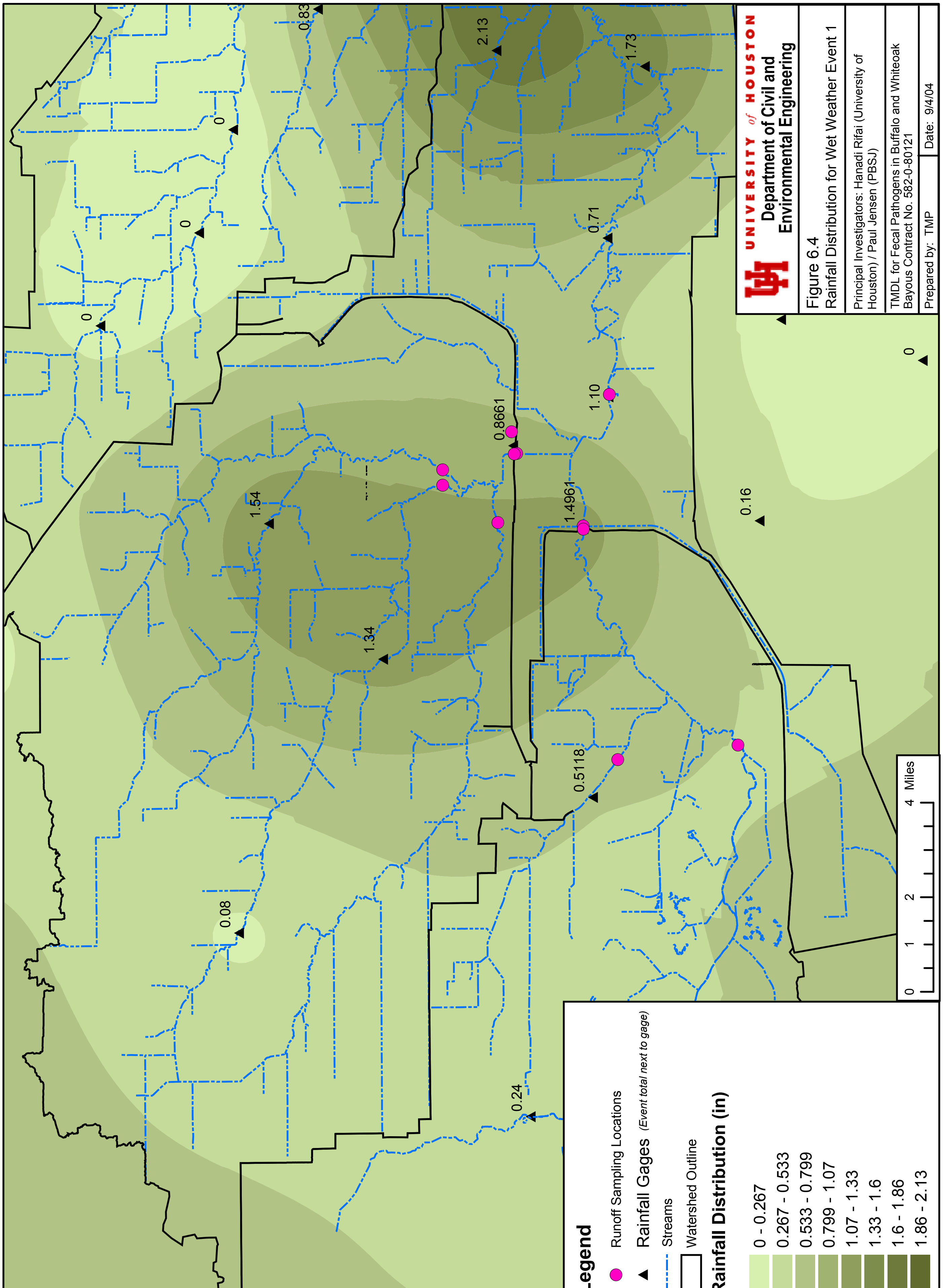
The Barker team started out by taking a sample at Dairy Ashford and then generally proceeded to collect samples at station 16428, followed by stations 11142 and 11165. The

Addicks team started sampling at the Addicks Discharge (TBD2) first, followed by sites 11164, 11158, and 11166. On the final runoff event, the Addicks team sampled site 11165 instead and the Barker team added a new site, Mason Creek (TBD4). The teams collected samples in this order until the flow subsided or the sampling locations got too dark to safely collect samples. AS a minimum, three rounds of sampling were conducted at each location.

6.3.1 WET WEATHER EVENT 1

The first runoff event was conducted on July 25, 2004. During this event, an average of 0.994 inches of rain fell across the reservoir watersheds. Figure 6.4 presents the rainfall distribution across the watershed, as calculated by a simple Kriging methodology in ArcGIS 8.1. As the figure shows, the Addicks watershed received more rain than the Barker watershed and the largest concentration of rain fell east of the reservoir discharge points. Three rounds of sampling were conducted during this event.

The rainfall during this event commenced around 3:50 PM and the rain ended around 16:30, as shown in Figure 6.5. The first samples were collected around 4:10 PM. The flows at Dairy Ashford responded quite quickly to the rainfall, with an increase in flows from 153 cfs at 4:00 PM to 610 cfs at 4:30 PM. The flows at Dairy Ashford continued to increase until 7:30 PM, at which point the hydrograph begins to recede. The reservoirs do not appear to respond as strongly to the rainfall as Dairy Ashford, possibly due to flows being reported on a 6-hour basis rather than the 30-minute intervals used to report bayou flow. The Addicks discharge increased from 158 cfs at 12:00 to 207 cfs at 6:00 PM, while Barker exhibited an increase in flows from 50 cfs to 175 cfs. Flows from the reservoirs continued to increase until 6:00 the next morning, with a maximum discharge from Addicks of 486 cfs and from Barker of 243 cfs. Sampling continued


UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 6.4
Rainfall Distribution for Wet Weather Event 1
Principal Investigators: Hanadi Rifai (University of Houston) / Paul Jensen (PBSJ)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous Contract No. 582-0-80121
Prepared by: TMP
Date: 9/4/04
Legend
Runoff Sampling Locations
Rainfall Gages (Event total next to gage)
Streams
Watershed Outline
Rainfall Distribution (in)
0 - 0.267
0.267 - 0.533
0.533 - 0.799
0.799 - 1.07
1.07 - 1.33
1.33 - 1.6
1.6 - 1.86
1.86 - 2.13
0
1
2
4
Miles
0.83
2.13
1.73
0
0
0
0.71
1.10
0.8661
1.54
1.4961
0.16
0
1.34
0.5118
0.08
0.24

until 8:24 PM, at which point the samples were taken back to the University of Houston laboratory.

The results of the wet weather sampling for this event are presented in Table 6.4. The concentrations of EC noted during this event ranged from 21 MPN/dL to 93,768 MPN/dL The highest EC concentrations were observed at stations 11166 (Bear Creek) and 11362 (Dairy Ashford), while the lowest concentrations were observed at station 16428 (Buffalo Bayou at Westheimer). The highest levels of TSS and TDS were observed at station 11165 (South Mayde Creek), while the lowest were noted at 16428 (Buffalo Bayou at Westheimer). Phosphorous concentrations were more constant than EC, TSS and TDS across the watersheds, but the maximum concentrations of 5.1 mg/L was noted at station 11166 (Bear Creek) while the lowest concentration of 0.3 mg/L was noted at site 11164 (Turkey Creek).

The interaction between EC concentrations, flows (if available) and rainfall can be observed in Figure 6.5. In general, the plot demonstrates that the runoff concentrations were much higher than those observed during dry weather on the previous day. All the sites in Addicks Reservoir demonstrated increasing trends in EC concentration, except for Langham Creek. In the Barker Reservoir watershed, Barker Discharge exhibited decreasing trends, while Buffalo Bayou at Westheimer showed increasing trends.

Figures 6.6 and 6.7 present plots of the phosphorous and TSS concentrations from this runoff event. Phosphorous concentrations generally exhibited decreasing trends, with increasing then decreasing trends also noted. TSS concentrations also exhibited impacts associated with rainfall runoff. Stations 11142 (Barker Discharge), 11158 (Langham Creek), 11166 (Bear Creek) and 16428 (Buffalo Bayou at Westheimer) exhibited decreasing trends while Addicks Discharge (TBD2) and station 11362 (Dairy Ashford) exhibited increasing trends. TSS concentrations at

Table 6.4 Wet Weather Reservoir Water Quality - Event 1

Date	Time	Station[c]	Total Coliform (MPN/dL)	*E. coli*[a] (MPN/dL)	TSS (mg/L)	TDS (mg/L)	Temp[b] (C)	Conductivity[b] (μs/cm)	DO[b] (mg/L)	pH[b]	Phosphorous (mg/L)
7/25/2004	4:10 PM	TBD 2	146809	1323	104	203	31.3	319	7.1	7.2	1.8
7/25/2004	4:20 PM	11362	>241920	90817	216	118	-[b]	-[b]	-[b]	-[b]	2.5
7/25/2004	4:43 PM	11158	>241920	15105	260	254	29.2	365	4.6	7.4	3.9
7/25/2004	5:10 PM	11142	>241920	68670	702	306	-[b]	-[b]	-[b]	-[b]	1.2
7/25/2004	5:25 PM	11166	>241920	12855	1062	432	28.1	461	6.5	7.6	5.1
7/25/2004	5:35 PM	16428	8098	21	71.5	297.5	-[b]	-[b]	-[b]	-[b]	2.2
7/25/2004	5:50 PM	11164	>241920	5648	121	152	28.0	135	6.4	7.6	0.3
7/25/2004	6:06 PM	11362	>241920	53235	213	103	-[b]	-[b]	-[b]	-[b]	1.3
7/25/2004	6:14 PM	TBD 2	>241920	17005	269	180	28.2	243	7.3	7.5	0.8
7/25/2004	6:31 PM	11165	>241920	39330	1146	992	-[b]	-[b]	-[b]	-[b]	4.3
7/25/2004	6:35 PM	11164	>241920	9317	97	132	27.5	129	6.6	7.4	0.5
7/25/2004	6:46 PM	11142	>241920	30675	510	264	-[b]	-[b]	-[b]	-[b]	1.8
7/25/2004	6:55 PM	11158	>241920	20445	192	216	28.1	321	4.6	7.3	3.5
7/25/2004	7:08 PM	11166	>241920	48840	320	83	26.7	97	6.8	7.7	1.3
7/25/2004	7:11 PM	16428	29610	119	58	305	-[b]	-[b]	-[b]	-[b]	1.9
7/25/2004	7:31 PM	TBD 2	>241920	18403	740	277	28.0	364	7.3	7.5	1.5
7/25/2004	7:40 PM	11362	>241920	34223	344	136	-[b]	-[b]	-[b]	-[b]	1.0
7/25/2004	7:51 PM	11164	>241920	17355	140	118	27.2	115	5.8	7.4	0.4
7/25/2004	8:10 PM	11142	>241920	30305	384	240	-[b]	-[b]	-[b]	-[b]	1.0
7/25/2004	8:15 PM	11158	>241920	4515	169	203	28.6	320	4.8	7.4	2.4
7/25/2004	8:18 PM	11165	>241920	51795	566	116	-[b]	-[b]	-[b]	-[b]	2.0
7/25/2004	8:24 PM	11166	>241920	93768	182	68	26.3	117	6.6	7.6	1.4
Sumary Statistics[d]											
Average			217318	30171	358	236	28.1	248.8	6.2	7.5	1.9
Geomean			184200	12612	257	194	28.1	217.3	6.1	7.5	1.5
Std Dev			67428	27680	309	192	1.3	125.3	1.0	0.1	1.3
Maximum			>241920	93768	1146	992	31.3	461.0	7.3	7.7	5.1
Minimum			8098	21	58	68	26.3	97.0	4.6	7.2	0.3

[a] *E. coli* concentrations have been rounded to 2 significant digits to meet TRACS reporting standards; duplicates were averaged and then rounded

[b] Probe parameters available only on half samples due to malfunctioning probe

[c] Stations correspond to the following locations:

11142	Barker Discharge	11362	Dairy Ashford	11165	S. Mayde Creek
11158	Langham Creek	16428	BB @ Westheimer	11166	Bear Creek
11164	Turkey Creek	TBD 2	Addicks Discharge	TBD4	Mason Creek

[d] Values greater than the detection limit were treated as the detection limit

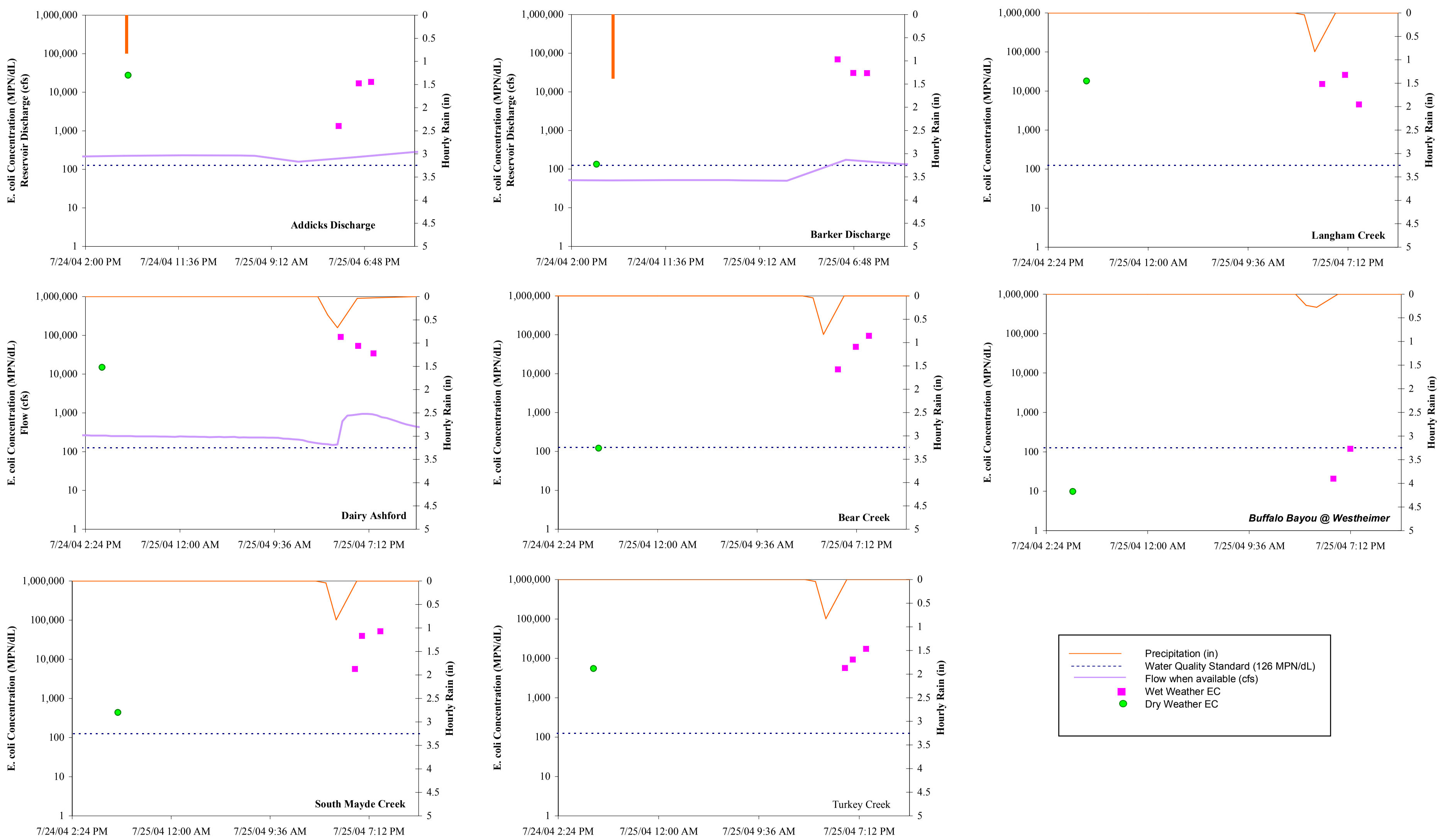


Figure 6.5 EC Concentrations for Runoff Event 1

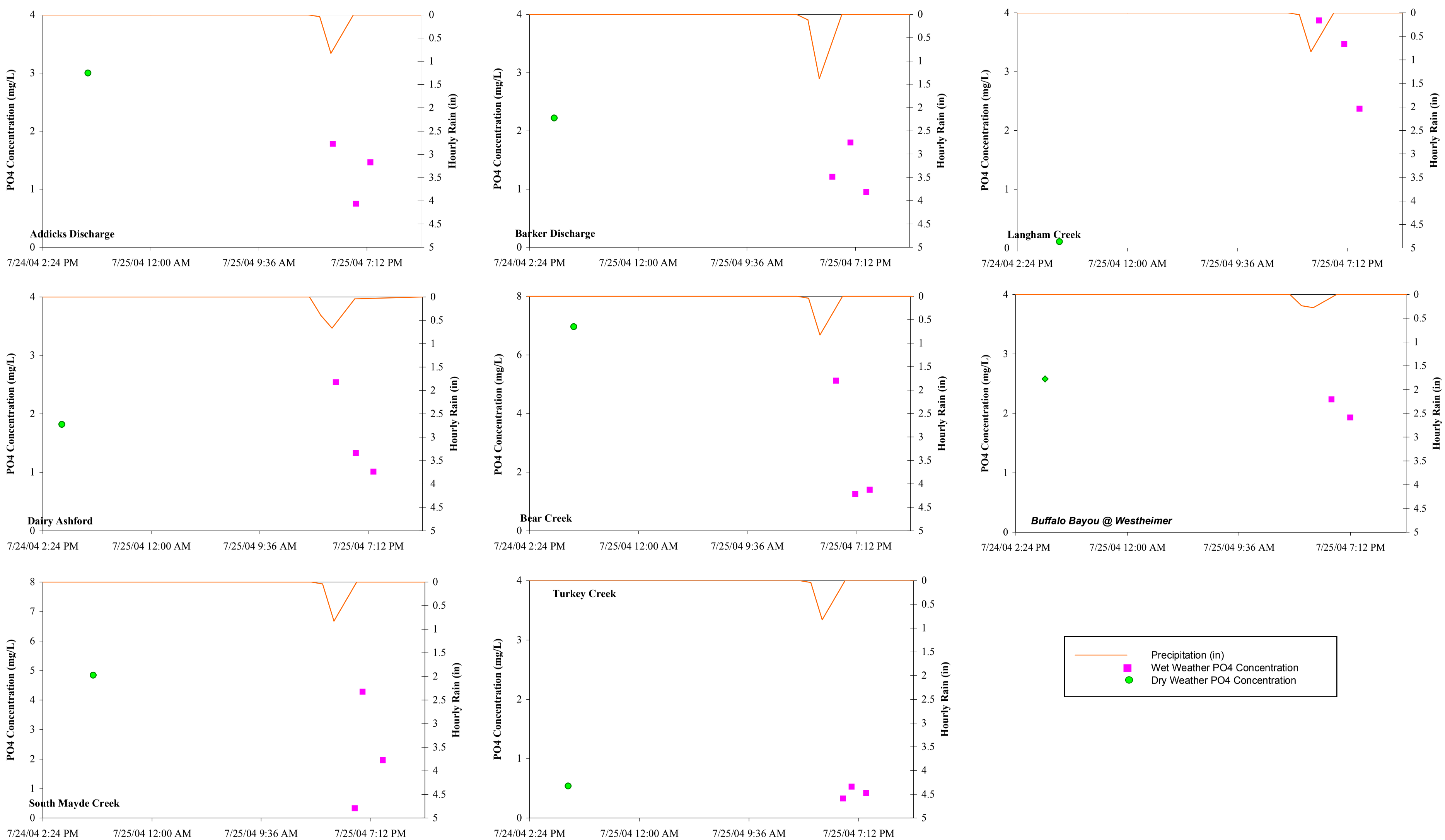


Figure 6.6 Phosphorous Concentrations for Runoff Event 1

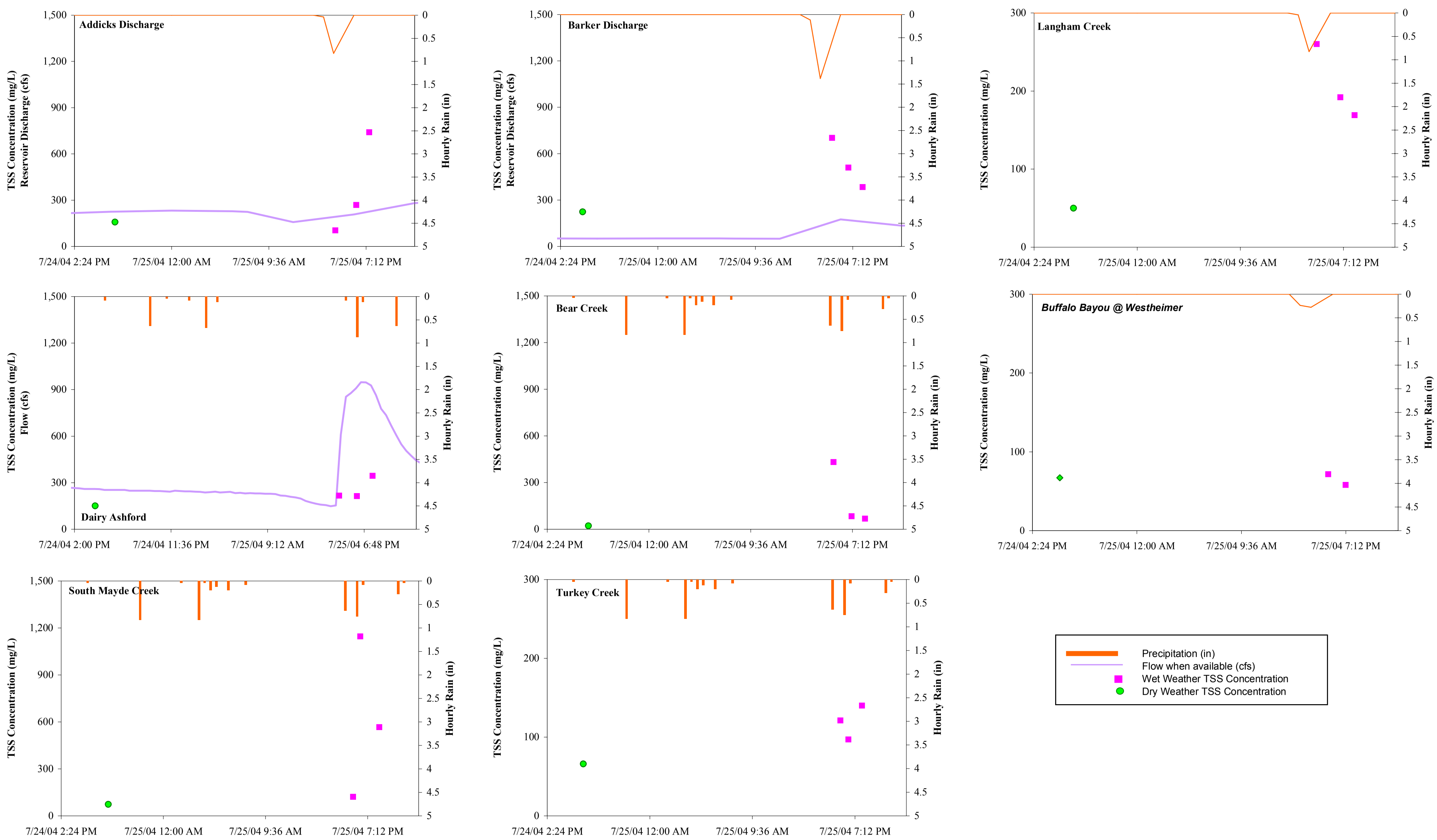


Figure 6.7 TSS Concentrations for Runoff Event 1

station 11165 demonstrated an increasing, then decreasing trend while concentrations at station 11164 (Turkey Creek) exhibited the opposite trend, decreasing then increasing.

There does not appear to be a common response to the rainfall between variables during this runoff event. Four sites (stations 11165, 11166, 11158, and 16428) exhibited similar trends between phosphorous and TSS. Station 11362 (Dairy Ashford) exhibited a similar trend between phosphorous and EC, while Addicks Discharge (TBD2) exhibited a similar trend between EC and TSS. Station 11164 (Turkey Creek) did not exhibit similar trends between any of the constituents.

6.3.2 WET WEATHER EVENT 2

The second runoff event was conducted on August 9, 2004. During this event, an average of 0.47 inches of rain fell across the reservoir watersheds. Figure 6.8 presents the rainfall distribution across the watershed. The maximum rainfall fell at the Addicks Reservoir discharge point, with the highest rainfall amounts extending northeast up into the Whiteoak Bayou watershed. The Addicks Reservoir watershed received more rainfall during this event than the Barker Reservoir watershed. Five to six rounds of sampling were conducted during this event.

The rainfall during this event commenced around 1:30 PM and the rain ended around 3:50 PM. The flows at Dairy Ashford responded a little more slowly than the previous event, with the increase in flow from 60 cfs to 73 cfs occurring at 3:00 PM. The flow continued to increase until 6:00 PM, with a maximum flow of 241 cfs. The reservoirs exhibited a similar, but slower, response to that observed at Dairy Ashford. The discharge from Addicks and Barker Reservoirs was reported to be 33 cfs and 34 cfs, respectively, at 12:00 PM on August 19. Both

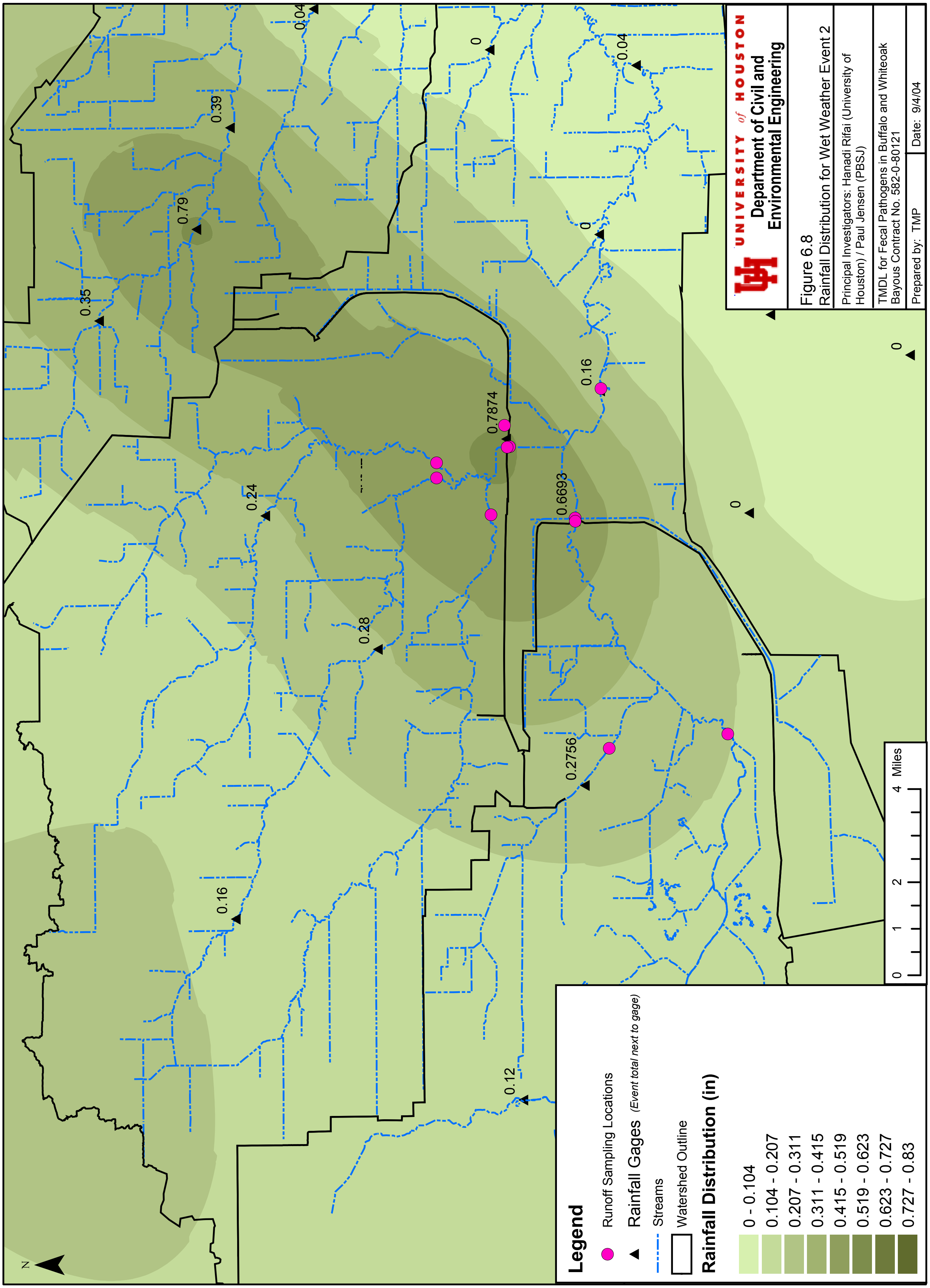


Figure 6.8
Rainfall Distribution for Wet Weather Event 2

discharges exhibited increasing trends until much later, with Addicks peaking at 113 cfs at midnight and Barker peaking at 106 cfs at 6:00 AM on August 20.

The first sample was collected at Dairy Ashford at 1:42 PM, which was still in the increasing portion of the hydrograph. Sampling continued until 8:09 PM in the Addicks Reservoir watershed and 10:17 PM in the Barker Reservoir watershed. Due to the extended sampling period, runners were dispatched to collect EC samples from the field teams to ensure the eight-hour holding time was met.

The results of the wet weather sampling for this event are presented in Table 6.5. EC concentrations ranged from 14 MPN/dL at station 16428 (Buffalo Bayou at Westheimer) to a maximum of 108,305 MPN/dL at station 11362 (Dairy Ashford). The maximum TSS concentration was noted at station 11362, while the lowest levels were noted at Station 11166 (Bear Creek). TDS concentrations ranged from 177 mg/L at station 11166 to 545 mg/L at station 11165 (South Mayde Creek). Phosphorous concentrations were slightly more variable than the previous runoff event, with a range of 6.9 mg/L to 0.2 mg/L reported and a standard deviation of 2.1 mg/L. Dissolved oxygen (DO) concentrations stayed fairly constant with time at each station. The maximum DO concentration reported was at station 16428, with a value of 8.0 mg/L which was above saturation for the stream temperature, and the minimum DO concentration was reported at station 11164 (Turkey Creek), with a value of 1.1 mg/L which was 13.5% of saturation.

The response of water quality variables EC, phosphorous and TSS with time are plotted in Figures 6.9, 6.10 and 6.11, respectively. As demonstrated in Figure 6.9, most sites during this event exhibited increasing and then decreasing concentrations of EC. Only station 11166 (Bear Creek) exhibited a different trend, with an increasing, decreasing and then increasing trend being

Table 6.5 Wet Weather Reservoir Water Quality - Event 2

Date	Time	Station[c]	Total Coliform (MPN/dL)	*E. coli*[a] (MPN/dL)	TSS (mg/L)	TDS (mg/L)	Temp[b] (C)	Conductivity[b] (μs/cm)	DO[b] (mg/L)	pH[b]	Phosphorous (mg/L)
8/19/2004	1:42 PM	11362	48840	494	49	354	27.5	859	6.4	7.6	4.4
8/19/2004	1:53 PM	TBD 2	79325	133	16	524	27.4	807	5.1	8.1	5.1
8/19/2004	2:04 PM	11142	103486	69	76	504	28.7	814	7.9	7.7	3.6
8/19/2004	2:15 PM	11164	26130	1516	8.4	264	26.5	387	1.1	7.4	0.2
8/19/2004	2:34 PM	11158	42290	155	16	231	28.7	880	3.8	8.2	6.4
8/19/2004	2:43 PM	16428	22390	14	47	461	29.1	719	7.3	8.2	3.2
8/19/2004	2:48 PM	11166	38730	135	6	483	27.6	753	3.0	7.7	2.4
8/19/2004	3:06 PM	TBD 2	>241920	521	37	509	27.3	767	5.0	8.1	5.5
8/19/2004	3:24 PM	11164	173287	28185	95	214	27.0	306	3.0	7.5	0.5
8/19/2004	3:29 PM	11165	185958	1166	46	457	26.7	722	6.8	7.9	3.9
8/19/2004	3:49 PM	11158	>241920	1184	81	459	28.3	804	3.9	8.2	5.7
8/19/2004	4:02 PM	11166	>241920	18060	114	242	27.3	474	3.8	7.7	1.8
8/19/2004	4:17 PM	11362	120331	8547	194	258	28.1	731	6.7	8.0	1.2
8/19/2004	4:30 PM	TBD 2	>241920	5889	110	511	27.4	750	5.2	8.1	5.0
8/19/2004	4:46 PM	11142	220273	4788	131	492	28.4	776	7.6	8.1	3.2
8/19/2004	4:47 PM	11164	>241920	6881	52	484	27.1	314	3.1	7.5	0.6
8/19/2004	5:03 PM	11158	176968	2198	43	465	28.5	815	3.8	8.1	6.2
8/19/2004	5:13 PM	11166	>241920	4691	58	531	27.7	703	3.5	7.7	2.5
8/19/2004	5:19 PM	16428	47475	504	36	367	23.3	777	8.0	8.6	2.9
8/19/2004	5:31 PM	TBD 2	>241920	4421	106	512	27.6	748	5.0	8.1	5.1
8/19/2004	5:45 PM	11164	>241920	7080	120	238	27.1	315	2.9	7.5	0.4
8/19/2004	5:55 PM	11165	130846	1454	37.2	490	27.1	754	6.3	7.9	6.8
8/19/2004	6:02 PM	11158	155307	3639	44	545	28.4	815	3.6	8.1	6.4
8/19/2004	6:15 PM	11166	241917	792	29	515	28.3	680	3.8	7.7	2.4
8/19/2004	6:27 PM	11362	>241920	91975	203	336	28.7	534	6.5	7.9	2.2
8/19/2004	6:42 PM	TBD 2	>241920	4796	100	258	27.6	751	4.9	8.0	5.3
8/19/2004	6:59 PM	11158	135663	1756	54	336	27.4	328	3.2	7.6	0.3
8/19/2004	7:01 PM	11142	198628	962	116	543	28.4	777	7.4	8.1	3.1
8/19/2004	7:13 PM	11164	198628	10225	43	483	28.4	816	3.5	8.0	6.3
8/19/2004	7:25 PM	11166	>241920	36830	38	177	28.0	353	2.8	7.5	1.4
8/19/2004	7:32 PM	16428	57940	179	48	460	29.4	721	7.7	8.5	2.8
8/19/2004	7:47 PM	TBD 2	241917	3030	73	471	27.5	744	4.8	8.0	5.1
8/19/2004	8:03 PM	11165	>241920	5634	58	473	26.9	742	5.5	7.8	6.6

Table 6.5 Wet Weather Reservoir Water Quality - Event 2, continued

Date	Time	Station[c]	Total Coliform (MPN/dL)	*E. coli*[a] (MPN/dL)	TSS (mg/L)	TDS (mg/L)	Temp[b] (C)	Conductivity[b] (µs/cm)	DO[b] (mg/L)	pH[b]	Phosphorous (mg/L)
8/19/2004	8:09 PM	11164	220273	10035	34	214	27.2	309	2.5	7.4	0.3
8/19/2004	8:18 PM	11362	241917	108305	131	178	28.3	389	6.1	8.2	1.8
8/19/2004	8:44 PM	16428	>241920	186	45	447	29.1	776	7.0	8.4	2.1
8/19/2004	9:07 PM	11142	77010	1166	143	400	27.9	759	7.1	8.1	3.5
8/19/2004	9:29 PM	11165	185958	3768	35	256	27.1	757	5.1	7.9	6.9
8/19/2004	9:48 PM	11362	>241920	19835	159	463	28.4	513	5.7	8.3	2.2
8/19/2004	10:17 PM	11142	126479	1085	152	532	27.8	725	7.3	8.0	2.7
Sumary Statistics[d]											
Average			196286	10057	75	403	27.7	661.6	5.1	7.9	3.5
Geomean			183294	2130	58	382	27.7	629.6	4.7	7.9	2.5
Std Dev			60890	22418	50	120	1.0	182.6	1.8	0.3	2.1
Maximum			>241920	108305	203	545	29.4	880.0	8.0	8.6	6.9
Minimum			57940	14	6	177	23.3	306.0	1.1	7.4	0.2

[a] *E. coli* concentrations have been rounded to 2 significant digits to meet TRACS reporting standards; duplicates were averaged and then rounded

[b] Probe parameters available only on half samples due to malfunctioning probe

[c] Stations correspond to the following locations:

11142	Barker Discharge	11362	Dairy Ashford
11158	Langham Creek	16428	BB @ Westheimer
11164	Turkey Creek	TBD 2	Addicks Discharge
11165	S. Mayde Creek	TBD4	Mason Creek
11166	Bear Creek		

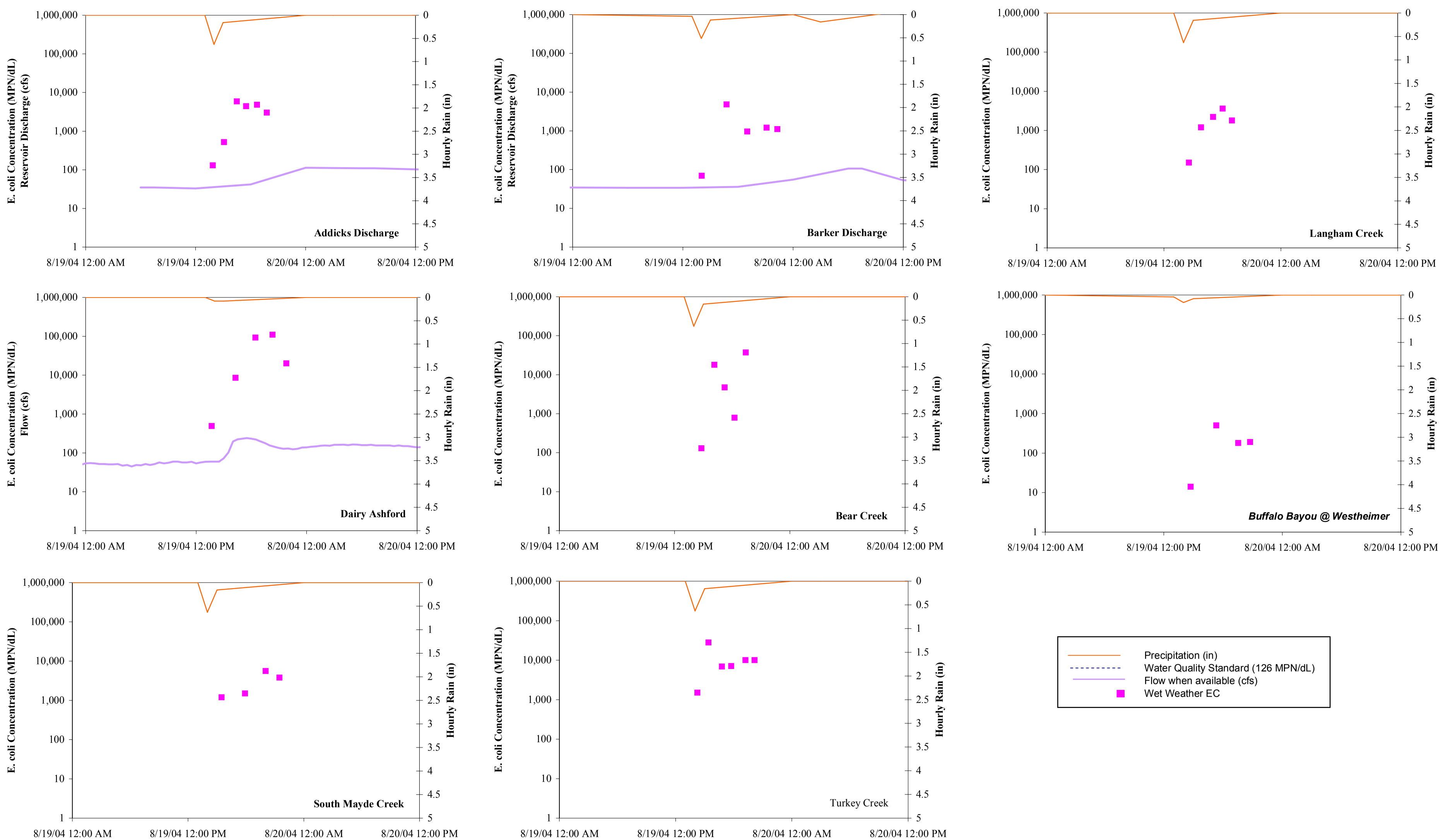


Figure 6.9 EC Concentrations for Runoff Event 2

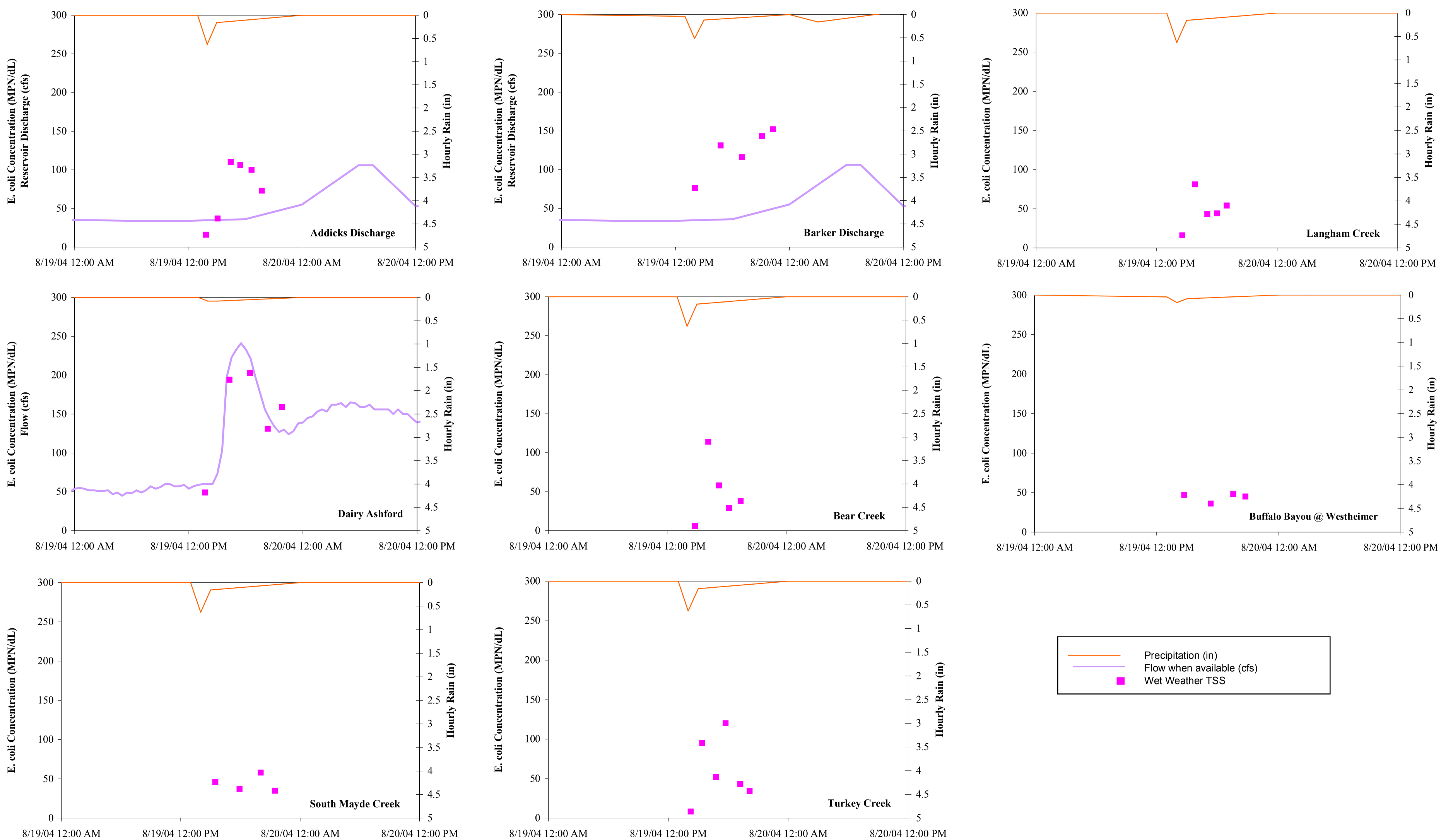


Figure 6.10 TSS Concentrations for Runoff Event 2

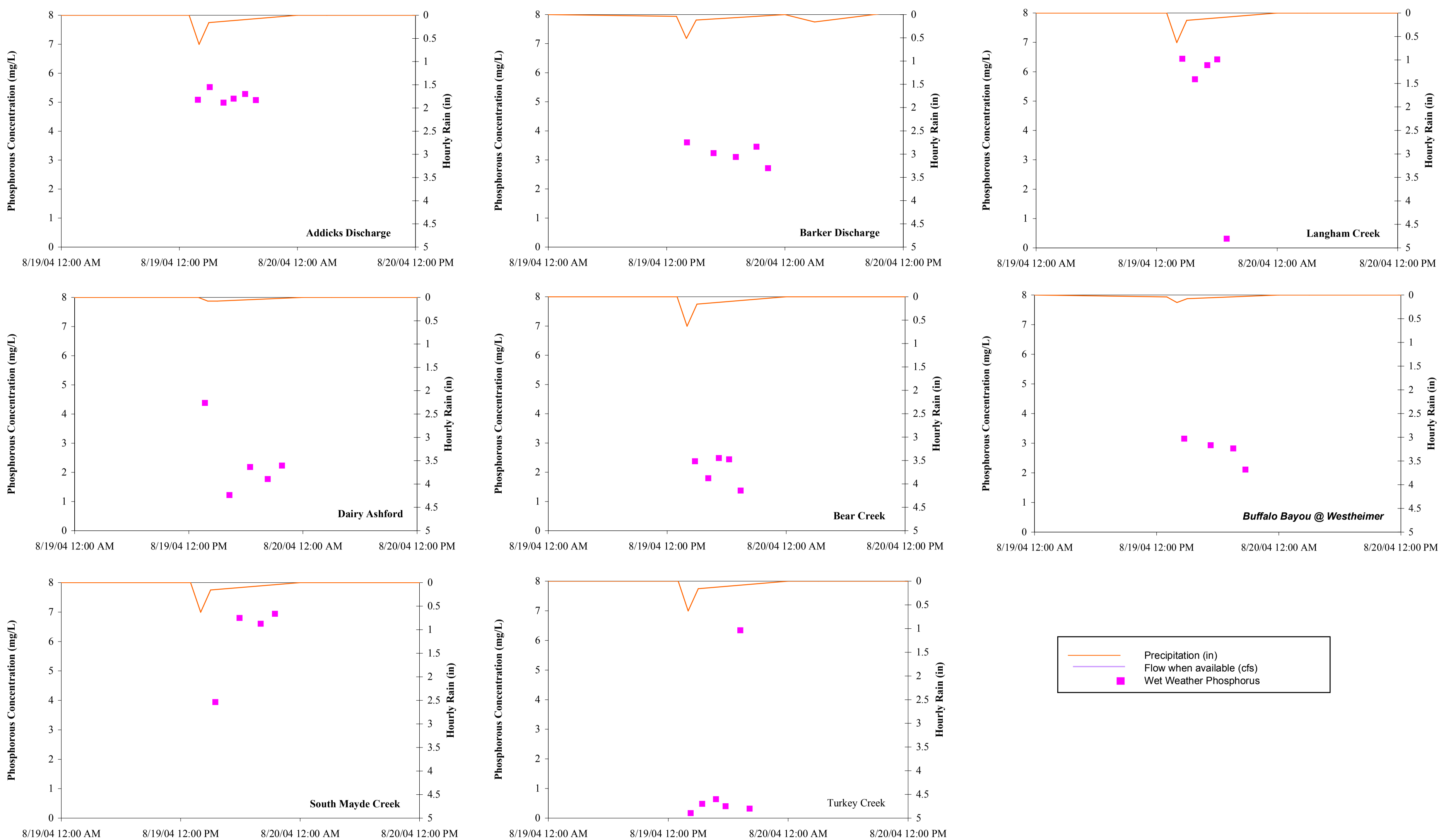


Figure 6.11 Phosphorus Concentrations for Runoff Event 2

observed instead. The trends present in EC appear to be related to flow, although they do not always mirror flows. EC concentrations at Dairy Ashford peaked almost one hour after the flow peaked, while the reservoir EC concentrations peaked almost 6 hours before the reservoir discharge flows did.

Figures 6.10 and 6.11 present plots of the phosphorous and TSS concentrations from this runoff event. TSS concentrations generally exhibited similar trends to those observed in EC concentrations. The overall trend tended to be an increasing, then decreasing pattern. Some stations, such as South Mayde Creek (11165) and Turkey Creek (11164) demonstrated patterns that were somewhat noisy, which might be related to the fact that the rainfall event did not extend into the upper watersheds of these streams . Phosphorous concentrations generally did not appear to be overly impacted by the rainfall event. Concentrations stayed fairly constant at several stations, with a few stations (Dairy Ashford, Turkey Creek, Langham Creek, South Mayde Creek) exhibiting an extreme low or high concentration occasionally during the event.

6.3.3 WET WEATHER EVENT 3

The third runoff event was conducted on August 28, 2004. During this event, an average of 0.67 inches of rain fell across the reservoir watersheds. Figure 6.12 presents the rainfall distribution across the watershed. The maximum rainfall fell southeast of the reservoir watersheds, with the maximum rainfall in the watersheds noted at Dairy Ashford, which received a total rainfall amount of 0.8662 in. Barker Reservoir received more rainfall than the Addicks Reservoir. Up to five rounds of sampling were conducted during this event.

The rainfall commenced around 2:30 PM and the rain ended around 18:25, with a fairly steady rainfall taking place in between. The flows at Dairy Ashford responded quite quickly to

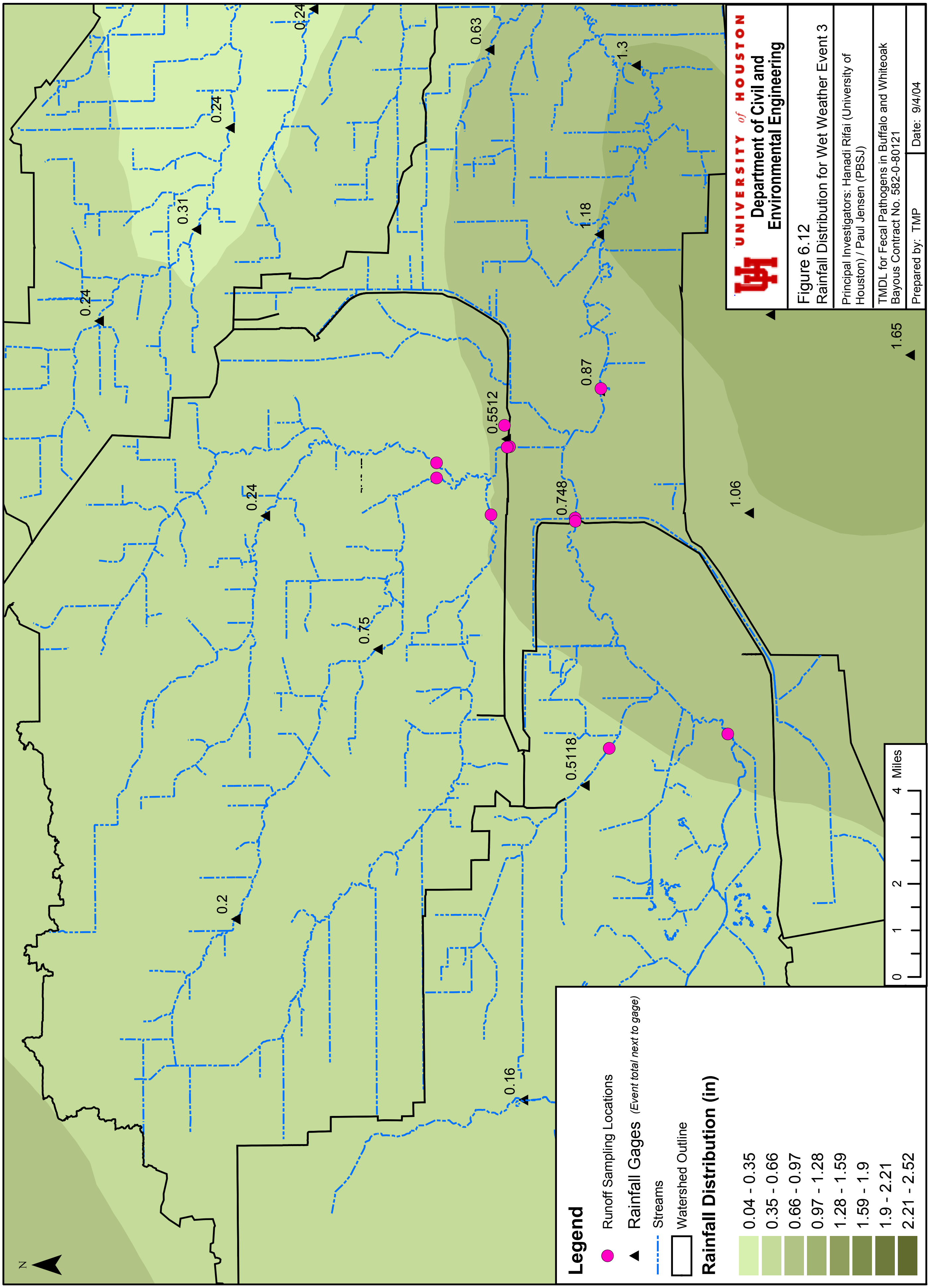


Figure 6.12
Rainfall Distribution for Wet Weather Event 3

the rainfall as shown in Figure 6.13, with the increase in flow from 51 cfs to 297 cfs occurring at 3:00 PM. The flow peaked at 3:30 PM, at which point the maximum flow of 434 cfs was reached. The flows at Dairy Ashford rebounded slightly around 6:30 PM, with an increase from 183 cfs to a secondary maximum of 219 cfs at 19:30. The U.S. Army Corps of Engineers closed the reservoir gates during this rainfall event. The Addicks Reservoir was closed around 5:30 PM and the Barker Reservoir was closed sometime after the Addicks Reservoir. The effects of the gates being closed on the flow at Dairy Ashford is evident in the very fast recession of the hydrograph. The Addicks and Barker pools stored a maximum of 208 and 246 acre-ft, respectively. The pools were emptied by 6:00 PM on August 30.

The first sample was collected at Dairy Ashford at 15:48, which was just after the flow at Dairy Ashford began to recede from the peak of the hydrograph. Although the sampling teams mobilized prior to the initiation of the storm at 14:00, traffic along Highway I-10 and Memorial Drive prevented the teams from arriving before the rain began. Sampling continued until 00:00 on August 29, 2004. Due to the extended sampling period, runners were dispatched to collect EC samples from the field teams to ensure the eight-hour holding time was met.

The results of the wet weather sampling for this event are presented in Table 6.6. EC concentrations ranged from 282 MPN/dL at station 16428 (Buffalo Bayou at Westheimer) to a maximum of 81,825 MPN/dL at station 11362 (Dairy Ashford). The maximum TSS concentration was noted at station 11165, while the lowest levels were noted at Station 11166 (Bear Creek). TDS concentrations ranged from 68mg/L at station 11166 to 992 mg/L at station 11165 (South Mayde Creek). Phosphorous concentrations ranged from 6.6 mg/L to 0.3 mg/L, values quite similar to the second runoff event. DO stayed fairly constant at the stream stations, but once the reservoirs were shut and pools began to form, the DO dropped. This was very

Table 6.6 Wet Weather Reservoir Water Quality - Event 3

Date	Time	Station[c]	Total Coliform (MPN/dL)	*E. coli* [a] (MPN/dL)	TSS (mg/L)	TDS (mg/L)	Temp[b] (C)	Conductivity[b] (μs/cm)	DO[b] (mg/L)	pH[b]	Phosphorous (mg/L)
8/28/2004	3:58 PM	11362	>241920	30820	128	275	28.2	300	6.7	7.7	2.2
8/28/2004	4:18 PM	TBD2	120979	1117	40	445	28.7	697	4.8	8.0	4.5
8/28/2004	4:32 PM	11164	176951	6092	87	253	27.9	288	2.5	7.5	0.3
8/28/2004	4:39 PM	TBD4	>241920	25780	200	363	29.8	429	5.0	8.2	6.6
8/28/2004	4:50 PM	11158	126674	3568	28	428	29.8	736	2.5	7.7	2.7
8/28/2004	4:59 PM	11166	108303	2427	15	437	28.6	755	2.9	7.7	1.9
8/28/2004	5:07 PM	16428	48396	282	108	375	30.0	475	2.8	8.0	2.8
8/28/2004	5:12 PM	11165	151626	1913	45	390	27.8	696	3.4	7.7	5.6
8/28/2004	5:36 PM	11164	112478	10905	53	273	27.5	290	2.2	7.5	0.6
8/28/2004	5:37 PM	11142	220273	7227	214	379	28.3	432	3.7	8.1	3.6
8/28/2004	5:55 PM	TBD1	137819	2213	42	425	28.1	688	3.7	7.8	4.3
8/28/2004	6:00 PM	11362	>241920	48840	99	216	28.4	262	3.4	8.1	1.6
8/28/2004	6:18 PM	11158	148334	3635	38	447	29.4	730	2.6	7.7	5.2
8/28/2004	6:35 PM	11166	120975	2109	17	422	29.2	712	3.9	7.8	1.1
8/28/2004	6:38 PM	16428	151626	504	81	368	29.8	471	1.9	8.0	2.9
8/28/2004	6:52 PM	11165	173287	1758	42	399	27.7	694	3.3	7.6	5.2
8/28/2004	7:06 PM	11142	164297	3107	82	341	27.1	416	1.9	8.0	3.6
8/28/2004	7:26 PM	11362	>241920	23995	114	269	28.4	331	1.9	8.0	1.9
8/28/2004	7:31 PM	TBD1	113871	2443	26.5	427	28.1	687	3.7	7.8	4.4
8/28/2004	7:48 PM	11164	142636	12605	56	264	26.6	282	2.5	7.8	0.7
8/28/2004	8:02 PM	TBD4	>241920	51720	120	344	27.9	272	1.6	8.2	3.3
8/28/2004	8:17 PM	16428	49207.5	310.925	105	388.5	30.1	478	1.1	8.0	0.9
8/28/2004	8:22 PM	11158	166375	2913.75	34.5	460.5	28.8	726	3.1	7.7	5.4
8/28/2004	8:48 PM	11166	241917	2258	14	434	27.3	456	3.1	7.9	1.2
8/28/2004	9:05 PM	TBD3	185958	3886	99	357	27.6	430	0.9	8.1	3.6
8/28/2004	9:09 PM	11165	130890	1318	55	394	27.3	679	3.2	7.6	4.9
8/28/2004	9:30 PM	TBD1	116158	1645	37	447	27.9	685	3.8	7.9	4.3
8/28/2004	9:48 PM	TBD3	198612	3097	88	381	27.6	430	0.4	8.0	3.7
8/28/2004	9:48 PM	11164	108305	8685	58	255	26.4	285	1.6	7.5	0.4
8/28/2004	9:48 PM	16428	198628	601	110	389	30.2	484	0.9	8.2	3.4
8/28/2004	10:07 PM	11362	>241920	81825	94	204	27.5	336	4.0	7.8	1.3
8/28/2004	10:27 PM	11158	198612	3744	55	459	28.4	730	2.6	7.7	5.0
8/28/2004	10:46 PM	11166	>241920	25770	18.5	440.5	28.2	755	2.9	7.7	2.0
8/28/2004	10:57 PM	TBD4	>241920	42425	137.5	249	27.7	250	0.6	8.6	2.9
8/28/2004	11:11 PM	11165	207602	1242	48	407	27.2	710	4.3	7.7	5.3
8/28/2004	11:18 PM	16428	102033	370	103	388	30.1	468	0.4	8.2	3.1
8/28/2004	11:33 PM	TBD1	>241920	30250	45	423	27.5	683	3.4	7.9	4.5
8/28/2004	11:44 PM	TBD3	120331	1980	102	386	27.2	431	0.0	8.1	3.4
8/29/2004	12:00 AM	11362	>241920	30250	97	239	27.3	381	4.1	7.9	0.9
Sumary Statistics[d]											
Average			182085	12452	75	365	28.2	513.8	2.7	7.9	3.1
Geomean			168682	4409	61	356	28.2	481.8	2.1	7.9	2.5
Std Dev			62690	18327	47	76	1.0	178.4	1.4	0.2	1.7
Maximum			>241920	81825	214	461	30.2	755.0	6.7	8.6	6.6
Minimum			49208	282	14	204	26.4	250.0	0.0	7.5	0.3

[a] *E. coli* concentrations have been rounded to 2 significant digits to meet TRACS reporting standards; duplicates were averaged and then rounded

[b] Probe parameters available only on half samples due to malfunctioning probe

[c] Stations correspond to the following locations:

11142	Barker Discharge	11362	Dairy Ashford
11158	Langham Creek	16428	BB @ Westheimer
11164	Turkey Creek	TBD 2	Addicks Discharge
11165	S. Mayde Creek	TBD4	Mason Creek
11166	Bear Creek		

[d] Values greater than the detection limit were treated as the detection limit

noticeable at the Barker Pool. The maximum DO concentration reported was at station 11362, with a value of 6.7 mg/L.

The response of water quality variables EC, phosphorous and TSS with time are plotted in Figures 6.13, 6.14 and 6.15, respectively. The variability in EC concentrations during this runoff event is apparent in Figure 6.13. All sites exhibit wet weather concentrations that are higher than those observed during dry weather sampling conducted the day before (August 27, 2004). Two sites (16428 and 11362) exhibit decreasing, increasing and then decreasing, while two sites (11164 and 11165) exhibit increasing concentrations and then decreasing concentrations. In Barker Reservoir, the concentrations exhibit a decreasing trend, both in the discharge and in the pool once the gates were closed. Addicks Reservoir, on the other hand exhibited increasing concentrations in the pool.

Individual station summary statistics are presented in Table 6.8. The station that exhibited the highest geometric mean EC concentrations was Mason Creek (TBD4), followed by station 11362 (Dairy Ashford), while the lowest concentrations were reported at station 16428 (Buffalo Bayou at Westheimer). TSS concentrations were found to be, on average, higher at station 11165 (South Mayde Creek) while the highest geometric mean TSS concentrations were noted at station 11142 (Barker Discharge) with a value of 251 mg/L. The lowest TSS concentrations were found at station 11166 (Bear Creek). TDS concentrations varied from 68 mg/L at station 11166 to 992 mg/L at station 11165. The highest concentrations of TDS, on average, were found at station 11165, with an average TDS of 437 mg/L. Phosphorous concentrations were highest on average at station 11158 (Langham Creek) and lowest at Station 11164 (Turkey Creek).

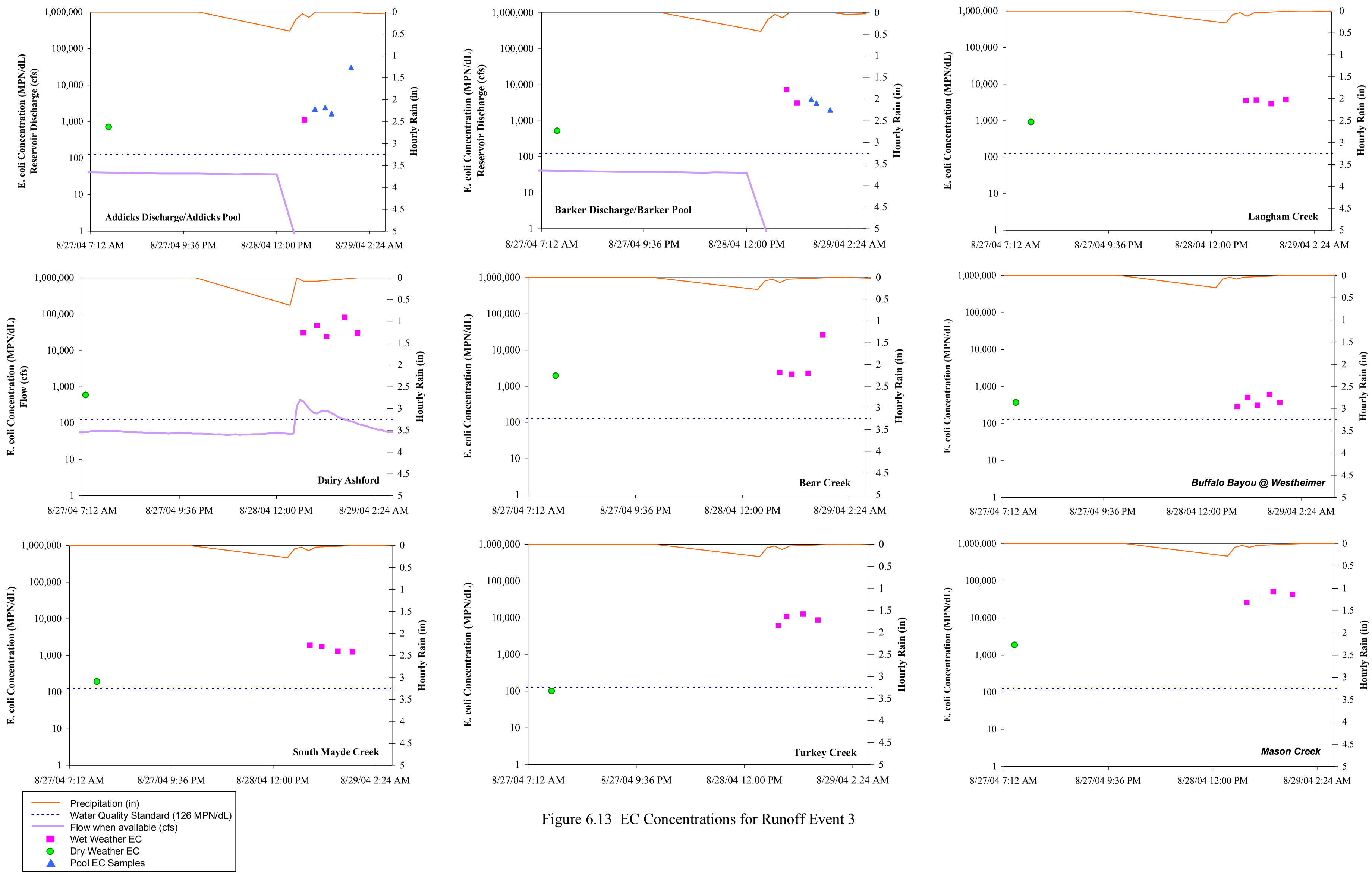


Figure 6.13 EC Concentrations for Runoff Event 3

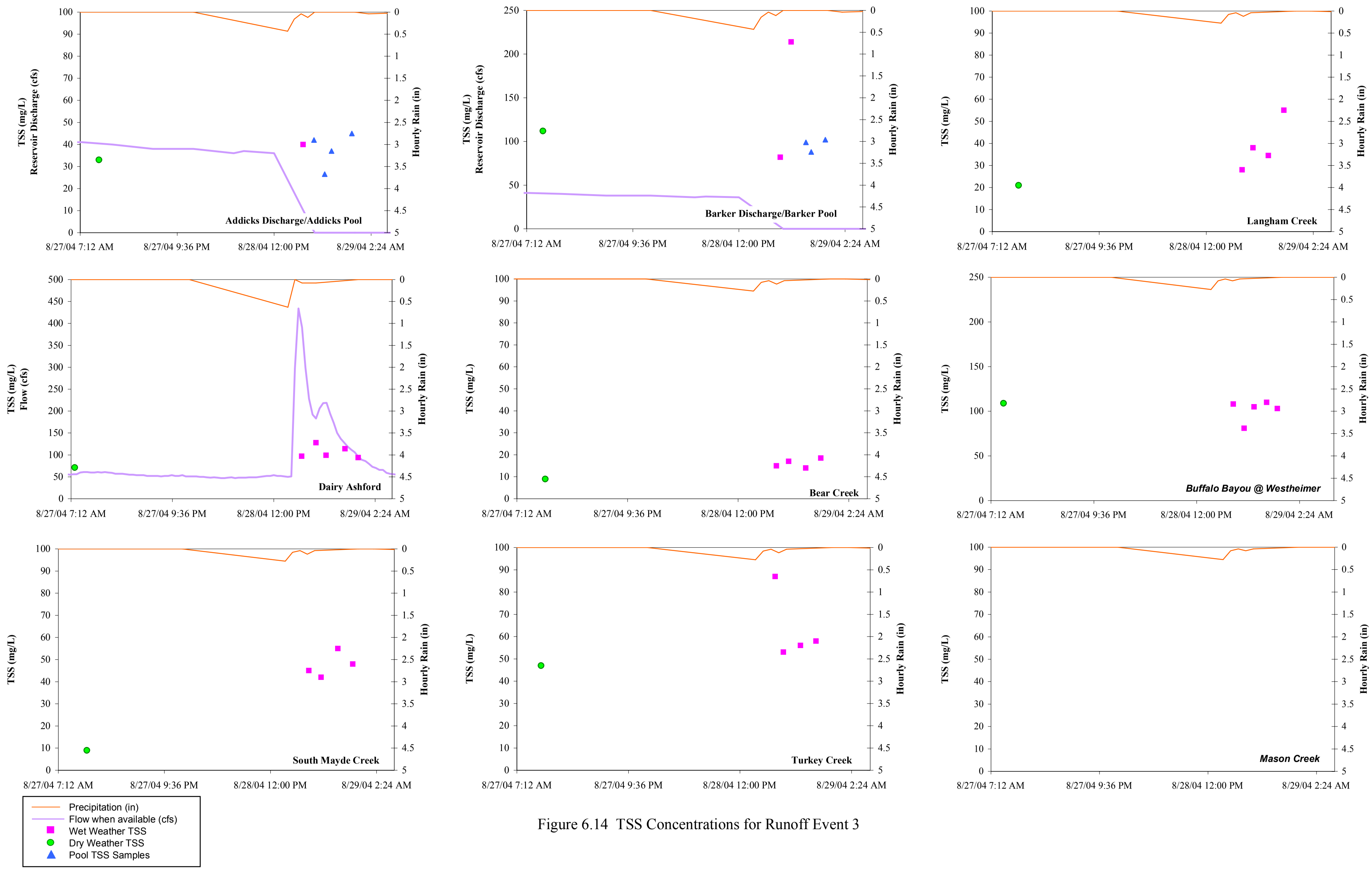


Figure 6.14 TSS Concentrations for Runoff Event 3

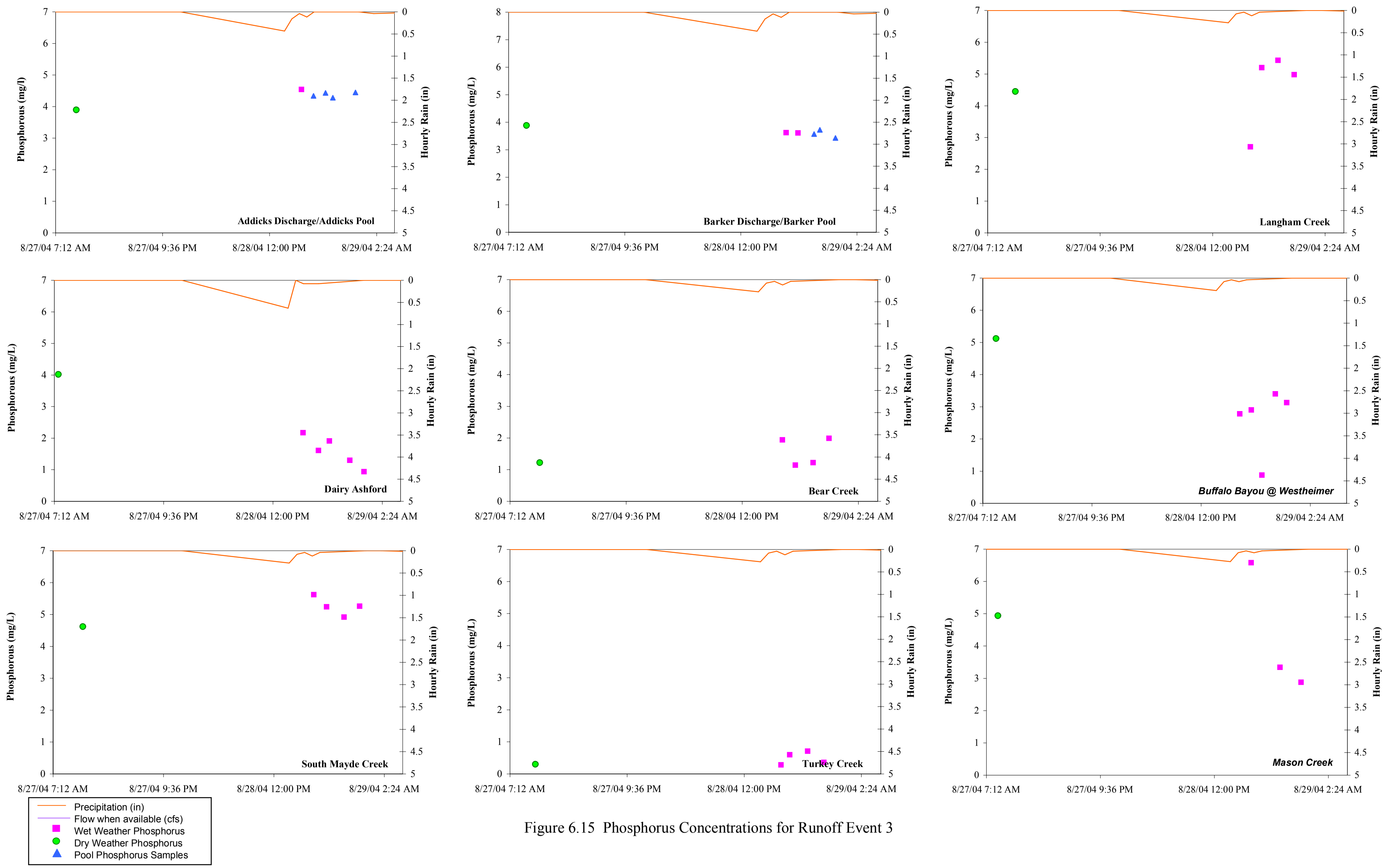


Figure 6.15 Phosphorus Concentrations for Runoff Event 3

6.3.4 WET WEATHER SUMMARY

Tables 6.7 and 6.8 present a summary of the wet weather sampling, with Table 6.7 demonstrating statistics for each parameter and Table 6.8 presenting statistics by each station. Overall, the EC concentrations were much higher than the water quality standards, with a geometric mean concentration of 4,165 MPN/dL. TSS concentrations were quite variable, with an average concentration of 175 mg/L found over all the stations. Phosphorous concentrations did not exhibit a very large range of concentrations, with an average of 3.0 mg/L and a standard deviation of 1.9 mg/L.

Wet weather summary statistics (Table 6.7), when compared with dry weather summary statistics (Table 6.2), appear to be different although no statistically significant differences arose. Average EC and TSS concentrations during dry weather were higher than those during wet weather. The average phosphorous concentrations stayed fairly constant between dry and wet weather sampling events, with a dry weather average concentration of 3.2 mg/L and a wet weather concentration of 3.0 mg/L.

Individual station summary statistics are presented in Table 6.8. The station that exhibited the highest geometric mean EC concentrations was Mason Creek (TBD4), followed by station 11362 (Dairy Ashford). The highest maximum EC concentration was reported at station 11166 (Bear Creek), while the lowest concentrations were reported at station 16428 (Buffalo Bayou at Westheimer). TSS concentrations were found to be, on average, higher at station 11165 (South Mayde Creek) while the highest geometric mean average TSS concentrations were noted at station 11142 (Barker Discharge). The lowest TSS concentrations were found at station 16428 (Buffalo Bayou at Westheimer). Phosphorous concentrations were highest on average at station 11158 (Langham Creek) and lowest at Station 11164 (Turkey Creek).

Table 6.7 Summary Statistics for Wet Weather Reservoir Sampling

	Average	Geometric Mean	Standard Deviation	Minimum	Maximum
Total Coliform (MPN/dL)	181467	158078	70834	8098	>241920
E. coli (MPN/dL)	15416	4165	23413	14	108305
TSS (mg/L)	175.0	98.0	230.7	6.0	1146.0
TDS (mg/L)	344.1	300.6	168.5	68.0	992.0
Temp (C)	28.0	28.0	1.1	23.3	31.3
Conductivity (µs/cm)	542.1	485.9	219.6	97.0	880.0
DO (mg/L)	4.5	3.5	3.5	0.0	8.0
pH	7.8	7.8	0.3	7.2	8.6
Phosphorous (mg/L)	3.0	2.2	1.9	0.2	6.9

Note: Samples greater than detection limit were treated as detection limit

Table 6.8 Statistics for Individual Stations - Wet Weather Sampling

Station	E. coli (MPN/dL)					TSS (mg/L)					TDS (mg/L)				
	Avg	Geometric Mean	Std Dev	Min	Max	Avg	Geometric Mean	Std Dev	Min	Max	Avg	Geometric Mean	Std Dev	Min	Max
11142 - Barker Discharge	14805	3768	22289	69	68670	251.0	189.8	211.6	76	702	400.1	385.1	112.5	240	543
11158 - Langham Crk	5683	3047	7365	155	25780	84.5	60.2	78.2	16	260	375.3	355.4	119.9	203	545
11164 - Turkey Crk	10348	8605	6567	1516	28185	74.2	61.5	38.9	8	140	257.2	236.9	112.9	118	484
11165 - S. Mayde Crk	10938	3635	18537	1166	51795	207.8	80.4	368.0	35	1146	437.4	388.3	224.8	116	992
11166 - Bear Crk	20711	6514	27929	135	93768	156.1	48.7	300.1	6	1062	355.4	297.8	166.4	68	531
11362 - Dairy Ashford	47935	29413	34832	494	108305	157.0	140.6	76.9	49	344	242.2	222.4	101.8	103	463
16428 - BB at Westheimer	281	178	199	14	601	73.9	68.6	28.7	36	110	386.0	382.4	54.8	298	461
TBD 2 - Addicks Discharge	5664	2560	6639	133	18403	159.5	91.6	215.6	16	740	389.0	361.6	141.6	180	524
TBD4[a] - Mason Crk	39975	38387	13142	25780	51720	153	149	42	120	200	319	314	61	249	363
Barker Reservoir Sites[b]	10212	1571	17821	14	68670	136.1	97.9	145.4	27	702	388.7	381.1	76.6	240	543
Addicks Reservoir Sites[c]	10829	4533	16336	133	93768	132.0	65.5	225.8	6	1146	357.5	318.0	161.4	68	992

Station	Phosphorous (mg/L)				
	Avg	Geometric Mean	Std Dev	Min	Max
11142 - Barker Discharge	2.73	2.49	1.03	0.95	3.62
11158 - Langham Crk	4.43	3.65	1.91	0.31	6.44
11164 - Turkey Crk	0.89	0.50	1.64	0.17	6.34
11165 - S. Mayde Crk	5.16	4.89	1.52	1.96	6.94
11166 - Bear Crk	2.04	1.86	1.09	1.14	5.12
11362 - Dairy Ashford	1.89	1.73	0.90	0.94	4.38
16428 - BB at Westheimer	2.57	2.43	0.73	0.88	3.40
TBD 2 - Addicks Discharge	3.96	3.33	1.85	0.75	5.52
TBD4[a] - Mason Crk	4.3	2.4	2.0	2.9	6.6
Barker Reservoir Sites[b]	3.11	2.88	1.14	0.90	6.60
Addicks Reservoir Sites[c]	3.16	2.09	2.25	0.20	6.90

[a] Only one sampling event was conducted at this site

[b] Barker Reservoir sites include 11142, 16428, TBD4

[c] Addicks Reservoir sites include 11158, 11164, 11165, 11166, TBD2

6.4 LOAD CALCULATIONS

Bacteria and TSS loads were calculated from the dry and wet weather data that were previously described. To calculate the loads, flows from the reservoirs as well as the Addicks and Barker Reservoir discharges were obtained. The EC and TSS concentrations were multiplied by the flow (and a conversion factor to obtain proper units) and the results are presented in Table 6.9. Summary statistics for the loads are presented in Table 6.10 and 6.11.

As shown in Table 6.10, the average and geometric mean loads observed for EC during dry weather are lower than those during wet weather, although this difference is not statistically significant ($p = 0.05$). TSS loads exhibited similar trends. Station 111362 (Dairy Ashford) demonstrated the highest loads of EC and TSS overall, with TBD2 (Addicks Discharge) exhibiting the lowest.

6.5 ADDITIONAL RESERVOIR SAMPLING

Houston experienced its second wettest June on record in 2004, second only to June 2001 when the city experienced Tropical Storm Allison. There were a total of 20 consecutive days of rain during the month, which resulted in a large amount of runoff from the Buffalo Bayou watershed. The U.S. Army Corps of Engineers made the decision to close the gates to Barker and Addicks Reservoirs several times during June, with the first occurrence on June 4, 2004. Figure 6.16 presents the reservoir storage and discharge for June 2004. As shown in Figure 6.16, the gates were closed and opened a total of six times, with the longest closure period around 6 days long. On July 1, 2004, the reservoirs were opened and left open to completely drain the pools that accumulated during June. The pools were finally emptied on July 20, 2004.

Table 6.9 Bacteria and TSS Loads for Reservoir Sampling

Date	Time	Station[a]	*E. coli* (MPN/dL)	TSS (mg/L)	Flow[b] (ft^3/s)	*EC Load* (MPN/hr)	*TSS Load* (mg/hr)
7/24/2004	4:05 PM	11362	14915	150	260	3.95E+12	3.98E+10
7/24/2004	4:35 PM	11142	133	223	237	3.21E+10	5.39E+10
7/24/2004	6:25 PM	TBD 2	27685	158	211	5.95E+12	3.40E+10
7/25/2004	4:10 PM	TBD 2	1323	104	207	2.79E+11	2.19E+09
7/25/2004	4:20 PM	11362	90817	216	610	5.65E+13	1.34E+10
7/25/2004	5:10 PM	11142	68670	702	175	1.23E+13	1.25E+10
7/25/2004	6:06 PM	11362	53235	213	909	4.93E+13	1.97E+10
7/25/2004	6:14 PM	TBD 2	17005	269	207	3.59E+12	5.68E+09
7/25/2004	6:46 PM	11142	30675	510	175	5.47E+12	9.10E+09
7/25/2004	7:31 PM	TBD 2	18403	740	207	3.88E+12	1.56E+10
7/25/2004	7:40 PM	11362	34223	344	927	3.23E+13	3.25E+10
7/25/2004	8:10 PM	11142	30305	384	175	5.41E+12	6.85E+09
8/9/2004	3:15 PM	TBD 2	105	22	31	3.33E+09	6.95E+07
8/9/2004	3:23 PM	11362	551	45	86	4.83E+10	3.95E+09
8/9/2004	3:45 PM	11142	96	104	38	3.71E+09	4.01E+09
8/19/2004	1:42 PM	11362	494	49	60	3.02E+10	3.00E+08
8/19/2004	1:53 PM	TBD 2	133	16	33	4.47E+09	5.38E+07
8/19/2004	2:04 PM	11142	69	76	34	2.40E+09	2.63E+08
8/19/2004	3:06 PM	TBD 2	521	37	33	1.75E+10	1.24E+08
8/19/2004	4:17 PM	11362	8547	194	223	1.94E+12	4.41E+09
8/19/2004	4:30 PM	TBD 2	5889	110	33	1.98E+11	3.70E+08
8/19/2004	4:46 PM	11142	4788	131	34	1.66E+11	4.54E+08
8/19/2004	5:31 PM	TBD 2	4421	106	33	1.49E+11	3.57E+08
8/19/2004	6:27 PM	11362	91975	203	221	2.07E+13	4.57E+09
8/19/2004	6:42 PM	TBD 2	4796	100	42	2.05E+11	4.28E+08
8/19/2004	7:01 PM	11142	962	116	36	3.53E+10	4.26E+08
8/19/2004	7:47 PM	TBD 2	3030	73	42	1.30E+11	3.13E+08
8/19/2004	8:18 PM	11362	108305	131	144	1.59E+13	1.92E+09
8/19/2004	9:07 PM	11142	1166	143	36	4.28E+10	5.25E+08
8/19/2004	9:48 PM	11362	19835	159	130	2.63E+12	2.11E+09
8/19/2004	10:17 PM	11142	1085	152	36	3.98E+10	5.58E+08
8/27/2004	7:44 AM	11362	592	71	56	3.38E+10	4.05E+08
8/27/2004	9:25 AM	11142	526	112	41	2.20E+10	4.68E+09
8/27/2004	10:00 AM	TBD 2	712	33	101	7.33E+10	3.40E+09
8/28/2004	3:58 PM	11362	30820	128	391	1.23E+13	5.10E+09
8/28/2004	4:18 PM	TBD2	1117	40	98	1.12E+11	4.00E+08
8/28/2004	5:37 PM	11142	7227	214	36	2.65E+11	7.85E+08
8/28/2004	6:00 PM	11362	48840	99	183	9.11E+12	1.85E+09
8/28/2004	7:06 PM	11142	3107	82	36	1.14E+11	3.01E+08
8/28/2004	7:26 PM	11362	23995	23995	219	5.36E+12	5.36E+11
8/28/2004	10:07 PM	11362	81825	94	128	1.07E+13	1.23E+09
8/29/2004	12:00 AM	11362	30250	97	96	2.96E+12	9.49E+08

[a] Sample IDs correspond to the following stations:
- 11142 Barker Discharge
- TBD 2 Addicks Discharge
- 11362 Dairy Ashford

[b] Reservoir Discharge recorded every 6 hours, USGS data reported every 30 minutes

Table 6.10 Summary Statistics[b] for Bacteria Loads

		***EC Load* (MPN/hr)**	***TSS Load* (mg/hr)**
Dry Weather	Average	1.12E+12	1.60E+10
	Geomean	6.63E+10	4.31E+09
	Std Dev	2.23E+12	2.06E+10
	Maximum	5.95E+12	5.39E+10
	Minimum	3.33E+09	6.95E+07
Wet Weather	Average	7.64E+12	2.06E+10
	Geomean	7.99E+11	1.69E+09
	Std Dev	1.38E+13	9.27E+10
	Maximum	5.65E+13	5.36E+11
	Minimum	2.40E+09	5.38E+07

Table 6.11 Individual Station[a] Summary Statistics[b] During Wet Weather

Station	***Statistic***	***EC Load* (MPN/hr)**	***TSS Load* (mg/hr)**
11142	Average	2.38E+12	3.18E+09
	Geomean	2.20E+11	1.11E+09
	Std Dev	4.12E+12	4.56E+09
	Maximum	1.23E+13	1.25E+10
	Minimum	2.40E+09	2.63E+08
TBD2	Average	8.57E+11	2.55E+09
	Geomean	1.75E+11	6.26E+08
	Std Dev	1.52E+12	4.90E+09
	Maximum	3.88E+12	1.56E+10
	Minimum	4.47E+09	5.38E+07
11362	Average	1.69E+13	4.80E+10
	Geomean	6.94E+12	5.01E+09
	Std Dev	1.83E+13	1.47E+11
	Maximum	5.65E+13	5.36E+11
	Minimum	3.02E+10	3.00E+08

[a] Stations correspond to the following locations:

11142 Barker Discharge
TBD 2 Addicks Discharge
11362 Dairy Ashford

[b] Summary statistics calculated using all data, both when reservoirs are open and when they are closed

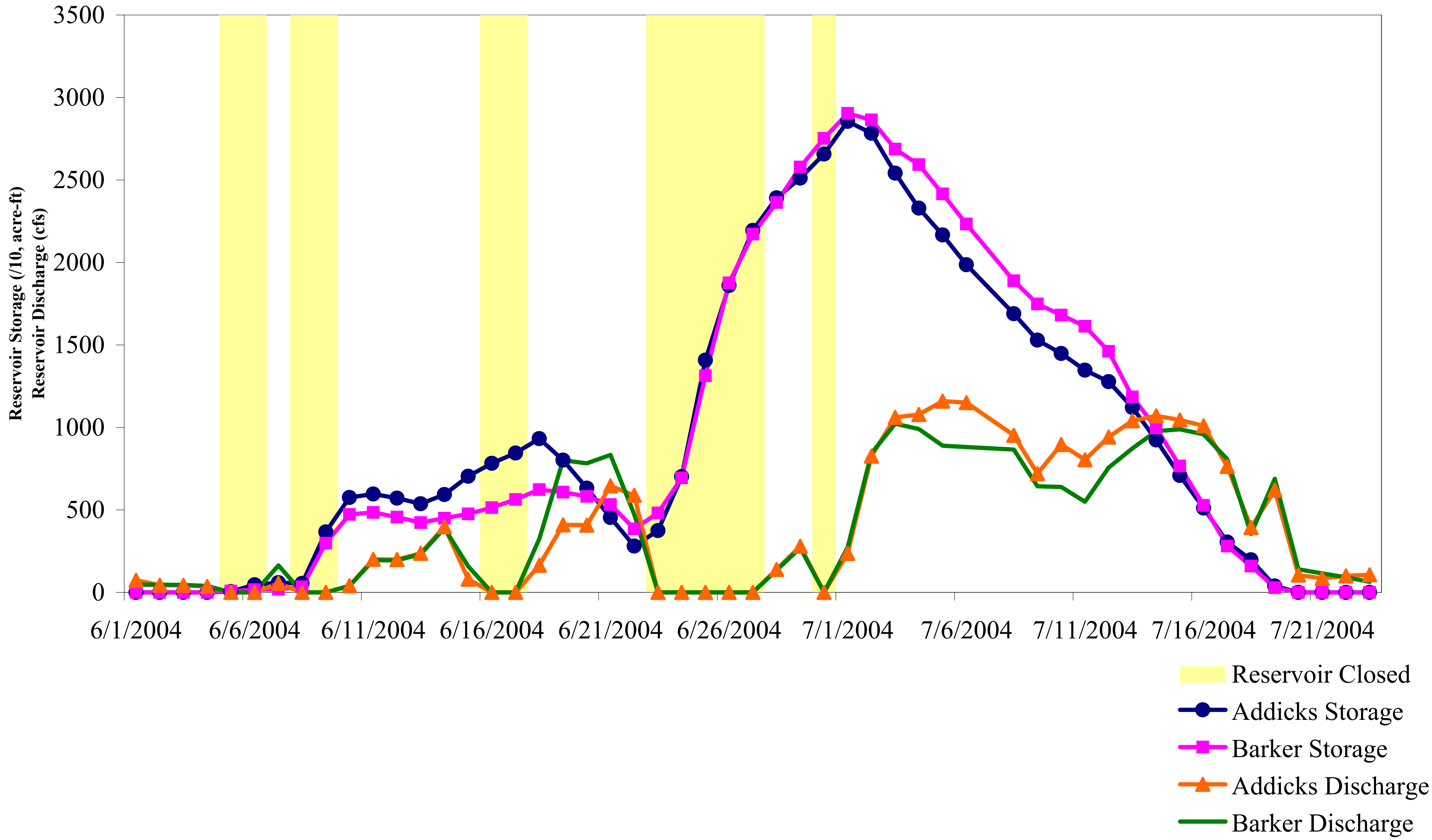


Figure 6.16 Reservoir Dynamics During June and July 2004

The presence of a pool for an extended period of time presented an opportunity to assess the ability of the reservoir pools to attenuate bacteria concentrations. Sampling of the reservoir pools commenced on July 1, 2004, the day that the reservoir gates were opened. Sampling focused on assessing the impact of the reservoirs on EC and TSS concentrations, and thus only the reservoir pools, reservoir discharges, and site 11362 (Dairy Ashford) were sampled. Water quality parameters that were measured included EC, TSS, TDS, and probe parameters. Initially, sampling was conducted every day until a baseline was established. Once it was apparent that concentration of EC stayed fairly constant, sampling was reduced to once every three days. When the reservoir pools were almost gone, sampling returned to once-per-day since the EC concentrations appeared to shift from the baseline concentrations.

Results of this sampling are presented in Table 6.12 and are plotted in Figure 6.17 for EC, Figure 6.18 for TSS and Figure 6.19 for TDS. Summary statistics are also presented in Table 6.13. In general, the concentrations of both EC and TSS were lower in the discharge when pools were present. These differences were statistically significant at the 95% confidence level ($p=0.05$). The reservoir pools also had very low concentrations, with none of the 22 samples exceeding the water quality standard. In fact, all pool samples were less than 56 MPN/dL. Although the discharge from the reservoirs was always below the EC water quality standard, the EC concentrations at Dairy Ashford were not. There was quite a bit of variation in the concentrations at Dairy Ashford, as can be noted from Figure 6.16. Six out of the eleven samples collected from Dairy Ashford when the pools were present exceeded the water quality standard. All samples collected once the pools were no longer present (including the dry weather samples described in Section 6.2) exceeded the water quality standard.

TSS concentrations during the post-June 2004 storms reservoir sampling, shown in Figure 6.18, exhibit trends similar to those observed in the EC data. TSS concentrations were quite low and maintained a fairly constant concentration during the time the pools were present (average concentration of 18.6 mg/L), but once the pools were fully drained, the TSS concentrations increased dramatically (average concentration of 236 mg/L). This difference in averages was statistically significant (p=0.05), similar to the case of EC.

Figure 6.19 presents the TDS concentrations for the same time period. The concentrations in the early part of July dropped off, and then slowly began to increase in all sampling locations. The concentrations did exhibit increases as the pools disappeared, but not in all locations (i.e., Addicks Discharge and Barker Pool).

Table 6.12 Results of Reservoir Sampling with Gates Open After June 2004 Rains

Date	Time	Station[a]	Total Coliform (MPN/dL)	*E. coli*[a] (MPN/dL)	TSS (mg/L)	TDS (mg/L)
7/1/2004	7:55	TBD3	26810	23	14.0	217.0
7/1/2004	8:08	11142	20385	25	21.0	202.0
7/1/2004	8:32	11362	>241920	5727	185.0	423.0
7/1/2004	9:12	TBD1	10310	23	11.0	174.0
7/1/2004	9:23	TBD2	6525	47	17.0	150.0
7/2/2004	9:15	TBD1	6643	7	11.0	157.0
7/2/2004	9:25	TBD2	2730	11	10.0	166.0
7/2/2004	9:55	TBD3	8460	9	11.0	211.0
7/2/2004	10:10	11142	14653	24	19.0	189.0
7/2/2004	10:35	11362	37270	198	33.0	206.0
7/3/2004	9:15	TBD1	14330	2	4.0	127.0
7/3/2004	9:24	TBD2	8490	16	5.0	112.0
7/3/2004	10:01	11142	13875	27	8.0	98.0
7/3/2004	10:17	TBD3	4359	2	11.0	137.0
7/3/2004	10:46	11362	21045	97	13.0	131.0
7/4/2004	7:57	TBD1	30305	<1	4.0	73.0
7/4/2004	8:06	TBD2	15530	9	5.0	111.0
7/4/2004	8:30	TBD3	4189	7	4.0	133.0
7/4/2004	8:38	11142	17825	27	6.0	105.0
7/4/2004	9:12	11362	28680	63	15.0	128.0
7/5/2004	8:35	TBD1	23945	2	5.0	84.0
7/5/2004	8:48	TBD2	9015	27	4.0	116.0
7/5/2004	9:30	TBD3	11980	13	8.0	115.0
7/5/2004	9:40	11142	6105	27	6.0	106.0
7/5/2004	10:15	11362	9790	47	14.0	129.0
7/6/2004	11:10	TBD1	24860	7	4.0	92.0
7/6/2004	11:20	TBD2	23820	18	< 4	119.0
7/6/2004	11:48	TBD3	13060	11	7.0	125.0
7/6/2004	11:59	11142	13515	56	7.0	107.0
7/6/2004	12:28	11362	26220	355	15.0	129.0
7/7/2004	9:10	TBD1	14215	2	5.0	105.0
7/7/2004	9:30	TBD2	10030	19	4.0	124.0
7/7/2004	10:10	TBD3	4352	7	6.0	122.0
7/7/2004	10:30	11142	7199	29	9.0	105.0
7/7/2004	11:10	11362	18890	245	13.0	133.0
7/9/2004	7:34	11362	18890	245	11.2	123.0
7/9/2004	8:00	TBD3	4482	7	5.6	111.0
7/9/2004	8:10	11142	6511	33	5.6	142.0
7/9/2004	8:35	TBD1	12225	29	4.4	134.0
7/9/2004	8:43	TBD2	9145	22	7.2	129.0
7/12/2004	7:48	11362	20785	129	17.2	116.0
7/12/2004	8:10	11142	5611	14	7.2	136.0
7/12/2004	8:35	TBD3	5062	8	9.6	111.0
7/12/2004	9:10	TBD1	8447	1	5.2	121.0
7/12/2004	9:20	TBD2	10860	9	8.0	125.0
7/15/2004	7:15	11362	14985	47	20.8	121.0
7/15/2004	7:55	11142	7631	7	13.2	103.0
7/15/2004	8:19	TBD3	10580	2	16.4	118.0

7/15/2004	8:55	TBD2	16665	19	11.6	129.0
7/15/2004	9:09	TBD1	13595	2	6.0	107.0
7/19/2004	6:55	11362	30050	81	30.0	196.0
7/19/2004	7:35	11142	12605	25	29.0	171.0
7/19/2004	8:19	TBD3	13100	16	24.0	153.0
7/19/2004	8:30	TBD2	5664	31	25.0	203.0
7/19/2004	8:45	TBD1	7814	32	37.0	194.0
7/20/2004	7:00	11362	133646	755	144.0	345.0
7/20/2004	7:23	11142	176968	424	688.0	315.0
7/20/2004	7:40	B	64157	339	360.0	334.0
7/20/2004	7:50	TBD3	173287	518	421.0	354.0
7/20/2004	8:35	A	159480	301	275.0	355.0
7/20/2004	8:51	TBD2	133646	224	275.0	355.0
7/21/2004	7:06	11362	137819	1050	168.0	512.0
7/21/2004	7:40	B	84140	250	283.0	412.0
7/21/2004	7:56	11142	146809	326	300.0	346.0
7/21/2004	8:31	TBD2	129966	254	93.0	439.0
7/22/2004	7:30	11362	241917	565	121.0	468.0
7/22/2004	8:03	11142	155307	297	258.0	382.0
7/22/2004	8:45	TBD2	129966	238	100.0	431.0
7/24/2004	16:05	11362	>241920	14915	150.0	194.0
7/24/2004	16:35	11142	137819	133	223.0	406.0
7/24/2004	18:25	TBD2	>241920	27685	158.0	156.0

[a] Stations correspond to the following locations:

11142	Barker Discharge
TBD 2	Addicks Discharge
11362	Dairy Ashford
B	Sample collected in Buffalo Bayou where Barker Pool was previously located
A	Sample collected from Langham Creek where Addicks Pool was previously located

Note: Pools no longer present on 7/20/04

Table 6.13. Summary Statistics for Comparison of Pools to No Pools

E. coli								
	Pools Present				Pools Not Present			
	Overall	TBD2	11362	11142	Overall	TBD2	11362	11142
Average	235	21	658	27	2747	3071	4870	300
Geomean	42	18	170	24	543	1139	551	255
Std Dev	989	11	1684	12	7100	5805	11179	165
Maximum	5727	47	5727	56	27685	14915	27685	526
Minimum	7	9	47	7	96	551	105	96
TSS								
	Pools Present				Pools Not Present			
	Overall	TBD2	11362	11142	Overall	TBD2	11362	11142
Average	18.6	9.7	33.4	11.9	189.9	125.6	129.6	314.5
Geomean	12.1	8.0	21.2	10.1	143.1	114.6	97.7	261.8
Std Dev	31.4	6.7	50.8	7.8	159.7	48.1	94.5	221.2
Maximum	185.0	25.0	185.0	29.0	688.0	168.0	275.0	688.0
Minimum	4.0	4.0	11.2	5.6	22.0	45.0	22.0	103.5

[a] Stations correspond to the following locations:

11142	Barker Discharge
TBD 2	Addicks Discharge
11362	Dairy Ashford

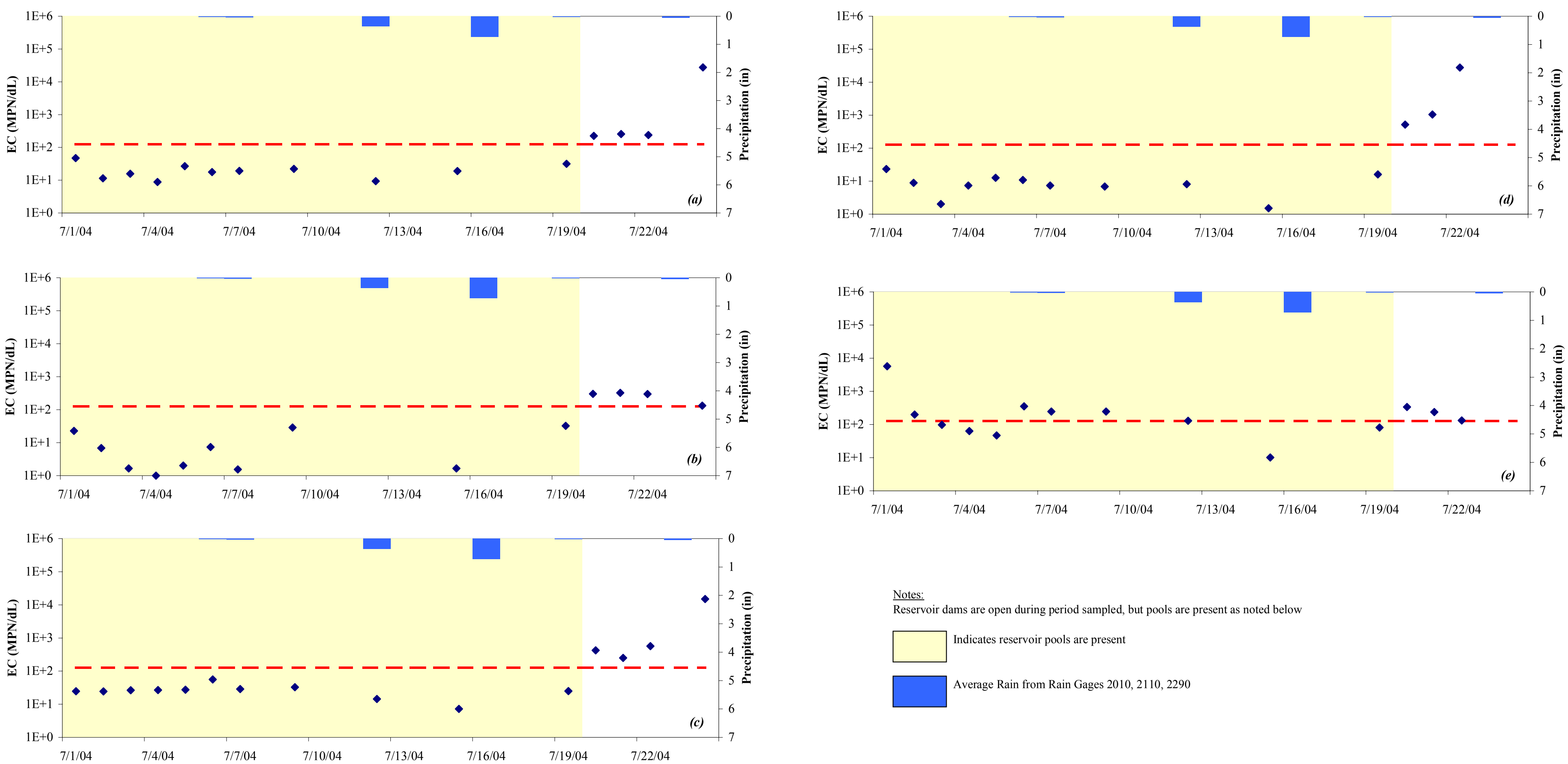


Figure 6.17 Reservoir Sampling for EC During Release after June 2004 Rains: (a) Addicks Discharge, (b) Addicks Pool, (c) Barker Discharge, (d) Barker Pool, (e) Dairy Ashford

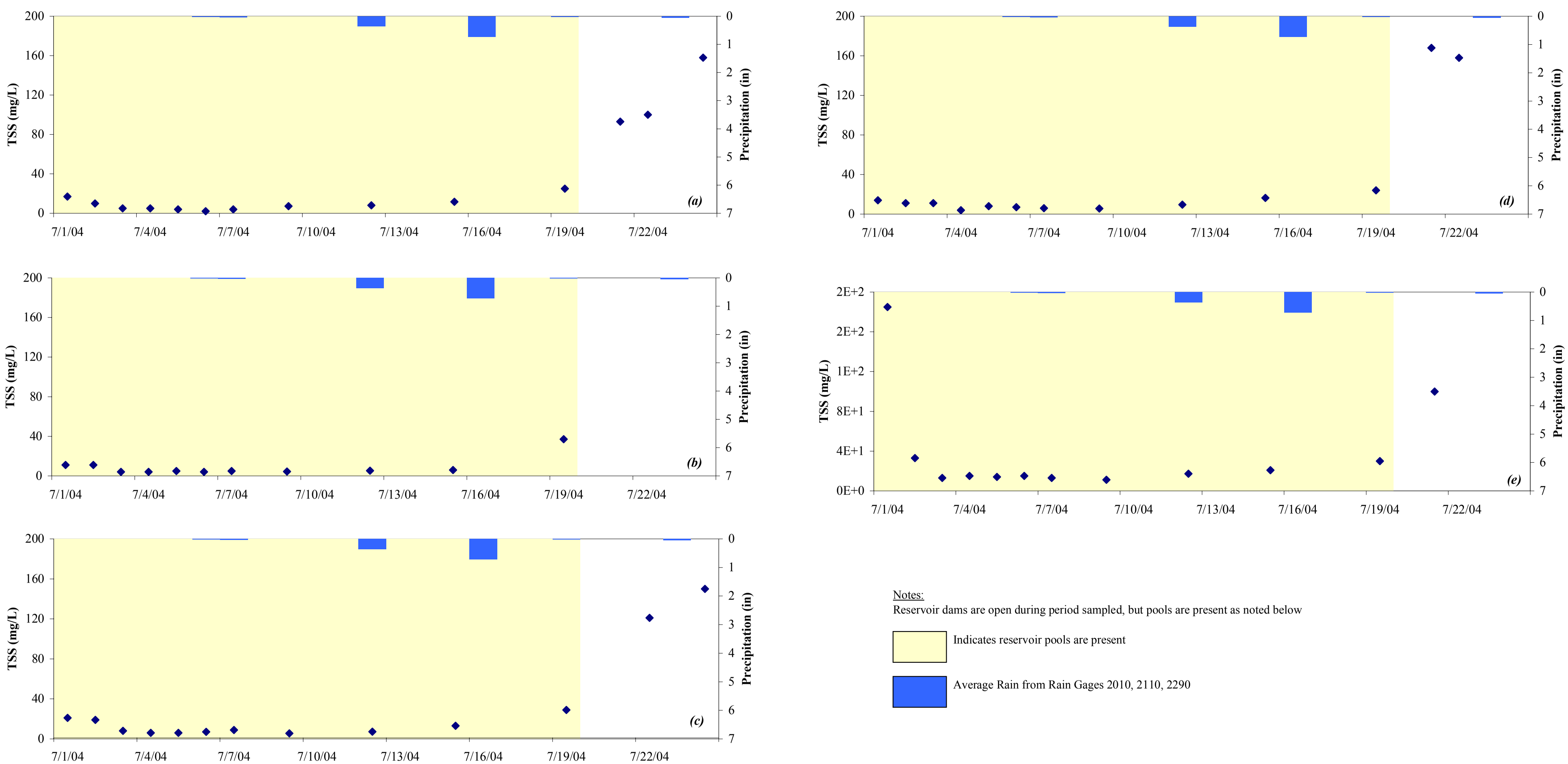


Figure 6.18 Reservoir Sampling for TSS During Release after June 2004 Rains: (a) Addicks Discharge, (b) Addicks Pool, (c) Barker Discharge, (d) Barker Pool, (e) Dairy Ashford

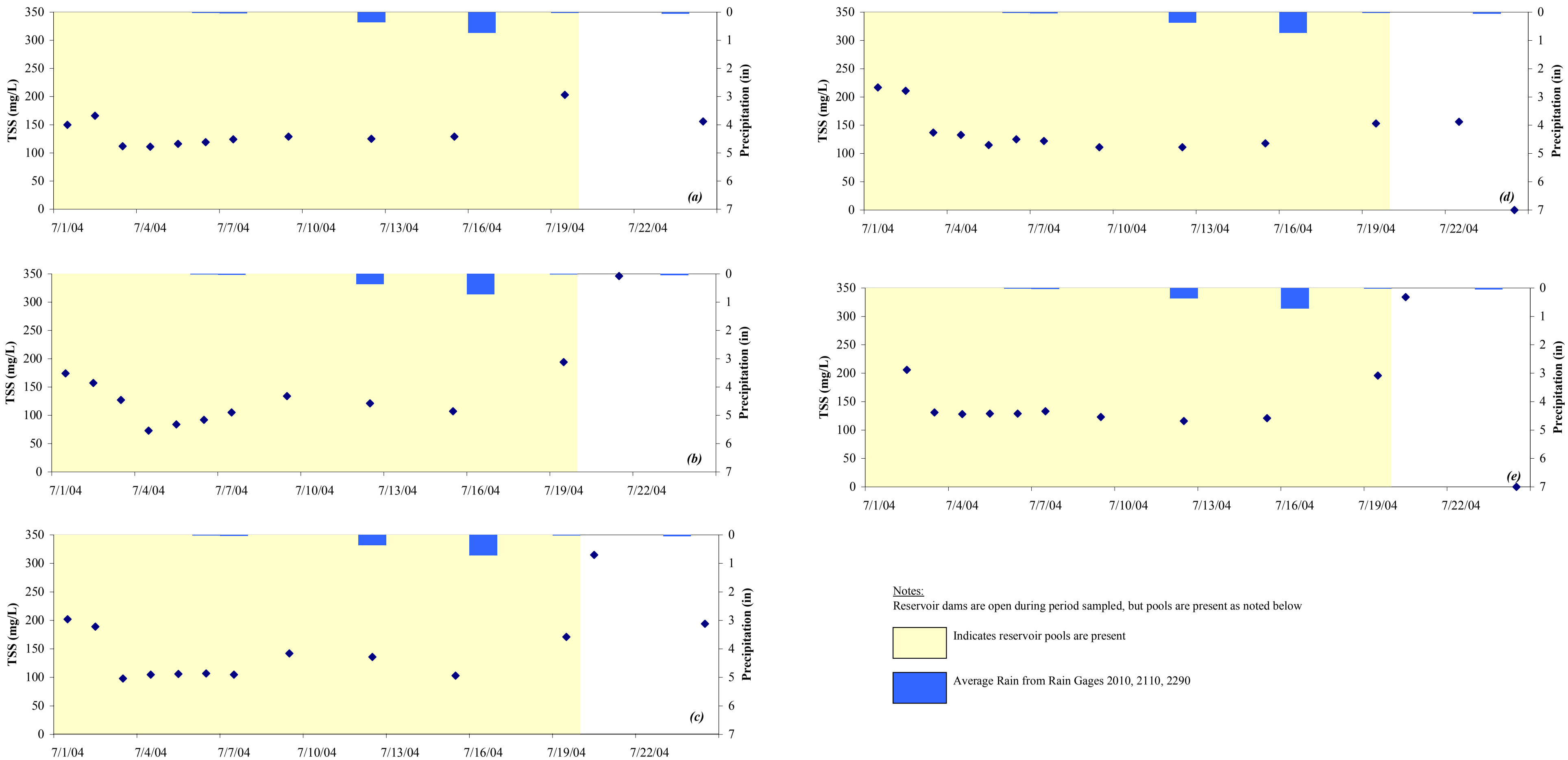


Figure 6.19 Reservoir Sampling for TDS During Release after June 2004 Rains: (a) Addicks Discharge, (b) Addicks Pool, (c) Barker Discharge, (d) Barker Pool, (e) Dairy Ashford

CHAPTER 7

QUANTIFICATION OF BACTERIA LOADS FROM OVERFLOWS AND BYPASSES

This section addresses the potential effects of inputs from the sanitary sewage system on indicator bacteria concentrations in area bayous and bayou sediments. The sanitary sewage system inputs considered include: untreated sewage bypasses at treatment facilities; releases of untreated sewage from the collection system during dry weather; and releases of untreated sewage from the collection system during wet weather. It concludes with a discussion of effects observed.

7.1 WWTP BYPASSES

The City of Houston was contacted to determine if bypass of raw sewage could occur through any of the wastewater treatment plants (WWTPs). The City confirmed that, except for the 69th Street WWTP, all WWTPs have no bypass or overflow structure that can allow bypass to occur (Hunt, 2004). All such structures were removed or closed in 1997 or earlier following a TCEQ enforcement order. It does not appear that a bypass of raw sewage during wet weather can physically occur in these WWTPs.

The 69th Street WWTP has a bypass/overflow structure permitted by TCEQ for wet-weather events. However, the structure is controlled by a sluice gate ahead of the bypass/overflow weir. The gate is normally closed so no automatic overflow can occur. A bypass can occur if the gate is opened manually. Any bypass will then be reported following the TCEQ permit. However, the City indicated that it has been a long time since the gate was opened

(Hyare, 2004). The gate was not opened during the Tropical Strom Allison event in June of 2001. Therefore, it can be concluded that no WWTP bypass has occurred in the study area in recent years.

7.2 DRY WEATHER SANITARY SEWER OVERFLOWS (SSOs)

There are two broad classes of SSOs - those that occur from a blockage or break without wet weather inflow and infiltration (I&I) influence and those related to a sewer capacity limitations brought on by high sewer flow rates in wet weather. Infiltration and inflow are terms that describe the movement of groundwater and stormwater into the sanitary sewer system. Infiltration is groundwater that enters sanitary sewers through leaks in pipe joints when groundwater is above the sewer elevation. Inflow is storm water that is directed to the sanitary sewers (illicitly) through connections such as roof downspouts, driveway drains and groundwater sump pumps. Wet weather SSOs brought on by high I&I are not addressed directly but a related situation is considered in Section 7.3.

The City of Houston (COH) was contacted to obtain a copy of the Sanitary Sewer Overflow (SSO) Excursion Report Database in Excel format. The database provided contains SSO excursion records reported during 1/1/2000 - 12/31/2003. Most of the excursions appear to be dry-weather events that occurred when a sanitary sewer line was blocked or broken. The Texas Commission on Environmental Quality (TCEQ) headquarters and its Houston regional office were also contacted to confirm that TCEQ has the same data set as COH and no additional SSO information was available in TCEQ databases.

To help determine the locations of SSO excursions and the potential for SSO to reach bayous, data from the Geographic Information and Management System (GIMS) of the COH were also obtained in Geographic Information System (GIS) shape file format (ArcMap). The files obtained from GIMS include the following:

- Sanitary Sewer Manhole Location Database, and
- Storm Sewer Location Database.

7.2.1 SUMMARY OF COH SSO EXCURSION DATA

The original SSO excursion database provided by COH contains 6,770 unique excursion records. Among them, 578 records were not associated with a Manhole Identification Number. These could have occurred at houses or the location simply could have been overlooked. These unknown excursions are apportioned to those where complete data are available. In addition, 8 records with no reported volume lost were identified as non-excursions based on a review of the "Excursion Cause Details" and/or "Corrective Action Details" fields. These 8 records were removed from further consideration.

The remaining SSO Excursion records were then segregated based on the manhole ID value. A total of 4,282 sanitary manhole locations were found to have at least one SSO excursion record. The geographic locations of these manholes were then determined by linking the data with the GIMS Manhole Location shapefile using the manhole IDs. However, 311 manholes (associated with 390 excursions) in the SSO Excursion database were found to possess manhole IDs that did not match any manhole IDs in the GIMs Manhole Location shapefile. The locations of these 311 manholes could therefore not be determined. Setting aside for the moment these 311 unidentifiable manholes, a total of 3,971 sanitary manholes were located in GIS. These 3,971 manholes are associated with 5,794 SSO excursion events.

7.2.2 COH SSO EXCURSIONS WITHIN BUFFALO BAYOU AND WHITE OAK BAYOU WATERSHEDS

The boundaries of Buffalo Bayou (BB) and White Oak Bayou (WOB) watersheds were overlapped with the SSO manhole locations to select those SSO excursions within the study area. The results of the GIS overlapping analysis show a total of 797 manholes with 1,180 SSO excursion records dated between 1/2/2000 and 12/30/2003 that are within the BB watershed, and 730 manholes with 1,078 records dated between 1/4/2000 and 12/18/2003 that are within WOB.

Figure 7.1 shows the resulting sanitary manhole locations within the BB and WOB watersheds where SSO excursions were reported. Different symbols were used in Figure 7.1 to identify different number of SSO excursion records associated with each manhole. Given that the database only covers areas within the city limits, Figure 7.1 shows gaps within the watersheds that are outside of COH limit.

7.2.3 ESTIMATION OF SSO FLOWS AND EC LOADS

Based on the data periods and an assumption that there are 250 dry days per year, SSO excursion flows can be estimated. The calculated total SSO reported volumes and flows are listed in Table 7.1. These give an average event volume of 2,729 gallons. This average event volume is then applied to the events that could not be specifically located. A total of 578 records that were not associated with manholes and the 390 excursions with unidentifiable manholes were considered in the average event volume. The total unidentifiable excursions (968) were apportioned to the study area based on the percentage for each basin (18.6% for Buffalo Bayou and 17.0% for Whiteoak Bayou) to yield the total volume shown in Table 7.1. This total volume was converted to an average flow using the assumption that these events only occurred on dry

Figure 7.1

Sanitary Manholes within BB and WOB Watersheds with SSO Excursion Records

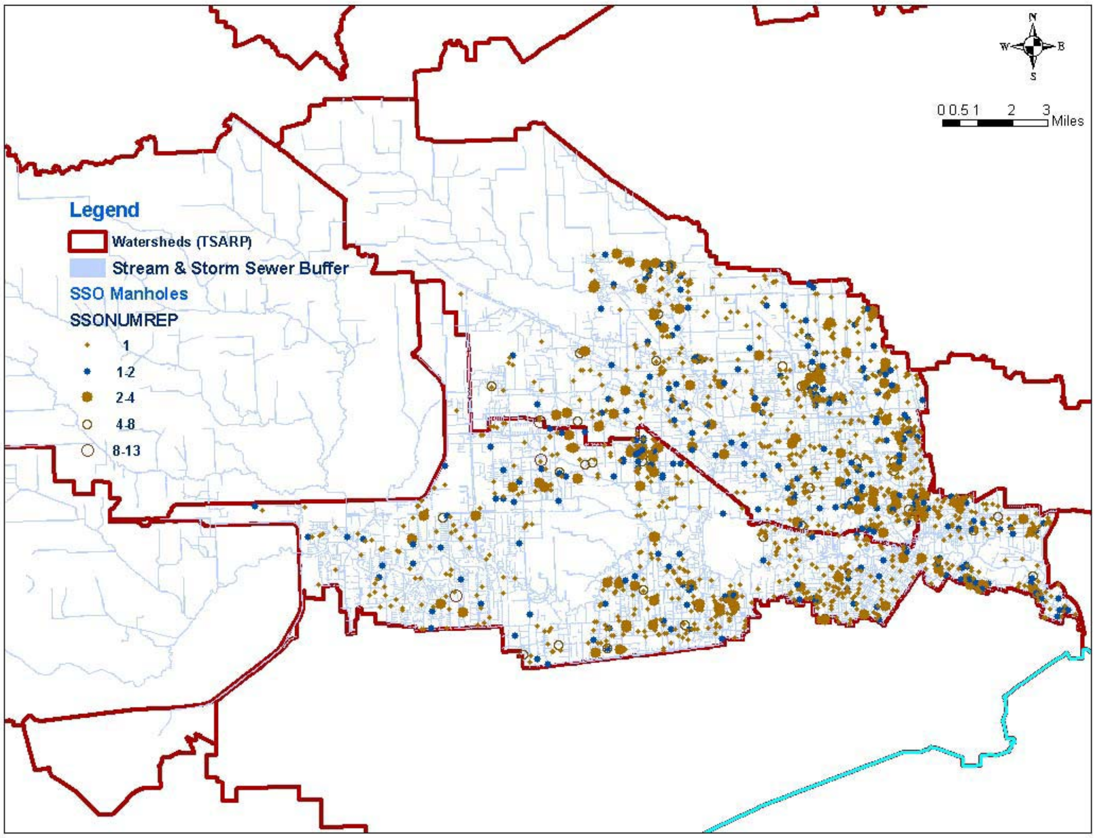


Table 7.1

Estimation of SSO Excursion Flows

Categories	SSO Vol (gal)	SSO Flow* (gal/day)	SSO Flow* (cfs)	Typ. Dry Flow (cfs)
Entire Database	16,876,954	16,877	0.0261	
Within BB	3,155,877	3,191	0.0049	100
Within WOB	2,386,960	2,390	0.0037	50

days and there were 250 of those per year. These average flows are very small, only 0.0049 and 0.0037 cubic feet per second (cfs) within BB and WOB watersheds, respectively. Compared to the typical dry-weather flows of about 100 and 50 cfs in BB and WOB, respectively, the SSO contribution is less than 0.01% in both bayous.

The SSO loads of E. coli (EC) bacteria can also be estimated. To quantify the levels of EC that could be expected in overflows, samples were collected from the City of Houston's Turkey Creek and West District facilities prior to treatment during dry weather. A total of six samples were collected, three from each plant. The results of the sampling are shown in Table 7.2. The EC concentrations ranged from 10^6 to 10^7 MPN/dL with a geometric mean of $5x10^6$ MPN/dL. Using EC = $5x10^6$ MPN/dL in SSO (raw sewage) and EC = 2,000 MPN/dL in the bayous, the concentrations of EC in BB and WOB including SSO contributions would be:

BB: $(5x10^6 * 0.0049 + 2{,}000 * 100) / (0.0049 + 100) = 2{,}245$ MPN/dL, or 12% increase.

WO: $(5x10^6 * 0.0037 + 2{,}000 * 50) / (0.0037 + 50) = 2{,}370$ MPN/dL, or 19% increase.

These calculations assume all SSO flow would enter the bayous. These results suggest that on a long-term average basis there is an increase in bayou EC levels due to SSO input.

In practice the bacterial contribution from sanitary sewer blockages and overflows will tend to be localized and may take a long time to show up as an overall percentage change. With a total of 6,184 sewer maintenance calls in a 4-year period, there is an average of 4.2 events/day in the city. The data suggest that about 35% of the events occurred in the BB-WOB study area or about 1.5 events per day as a long-term average. If the sewage from an event flows to a bayou, one would expect a significant increase in the concentration of indicator bacteria at the point of

TABLE 7.2
WASTEWATER SAMPLING DATA AT CITY OF HOUSTON FACILITIES

Station	Stationid	Date	Time	FC 31616 (cfu/dL)	EC 31699 (MPN/dL)	Days from last rain 72053	1-d prior rain 82553 (in)	7-d prior rain 82554 (in)
Turkey Cre	PBW02	08/04/04	11:30	1,980,000	3,230,000	6	0	0.65
Turkey Cre	PBW02	08/05/04	08:45	1,850,000	7,270,000	7	0	0.375
Turkey Cre	PBW02	08/06/04	10:30	580,000	7,113,500	8	0	0.16
West Distri	PBW03	08/04/04	12:15	1,780,000	7,485,500	4	0	0.55
West Distri	PBW03	08/05/04	09:15	1,500,000	1,152,750	5	0	0.51
West Distri	PBW03	08/06/04	11:30	1,550,000	9,616,333	6	0	0.16
West Distri	PBW03 spl	08/06/04	11:30		8,182,500			

Note:
Storet code shown under name of parameter.

entry and downstream until the flow is corrected. If no overflow event occurs or the overflow does not reach a bayou, there would be no increase in bayou indicator bacteria levels. The average increase calculations above are an attempt to put this variability into a long-term context using conservative assumptions, but it is obvious that significant variability is associated with this source.

7.2.4 POTENTIAL OF SSOS TO REACH BAYOUS

Some dry weather SSO excursions may not reach a bayou because their volume is too small (evaporated and/or infiltrated) or their location is too far from a pathway such as a ditch or a storm sewer line that can reach a bayou. When quantifying potential impacts it is conservative and appropriate to assume that all SSO flow would enter the bayous. However, when assessing the likely effect of a measure, a realistic estimate of the potential for the SSO excursions to reach the bayous can also be useful.

Two approaches were considered to determine such potential. The first was to sort the data within the SSO Excursion Database using the "Flow Location" field, which identifies the observed destination of the SSO excursion as recorded by field personnel. The second is to create a buffer zone along the storm sewer, ditch, and bayou lines, and identify the SSO locations that were well removed from a flow pathway (outside of the buffer zone) and thus will have little potential of reaching the bayous.

Table 7.3 shows the results of the first approach. The total number of SSO excursions and their volumes associated with each destination was calculated and listed in the table. A total of 529 and 493 records within BB and WOB watersheds, respectively, were found to have no documentation of the SSO destination. These SSO excursions are labeled as "Blank" in Table 7.3

Table 7.3

Potential of SSO To Reach Bayous Based on Destination Records

SSO Destinations	SSO Excursions	SSO Volume (gallons)	% of Total SSO Excursions		% of Total SSO Volume	
			w/ "Blank"	non-"Blank	w/ "Blank"	non-"Blank
Buffalo Bayou						
"Blank"	529	1,296,452	45%		49%	
Bayou	35	143,885	3%	5%	5%	10%
Contained On Site	169	207,788	14%	26%	8%	15%
Drainage Ditch	73	127,082	6%	11%	5%	9%
Storm Sewer	375	892,989	32%	58%	33%	65%
Total	**1181**	**2,668,196**	**100%**	**100%**	**100%**	**100%**
White Oak Bayou						
"Blank"	493	979,158	46%		51%	
Bayou	23	44,220	2%	4%	2%	5%
Contained On Site	154	190,409	14%	26%	10%	20%
Drainage Ditch	95	159,149	9%	16%	8%	17%
Storm Sewer	311	538,335	29%	53%	28%	58%
Total	**1076**	**1,911,271**	**100%**	**100%**	**100%**	**100%**

Table 7.3 also lists the percentages of SSO associated with a bayou, storm sewer, or drainage ditch destination, as well as those documented as "contained on site". The percentages were calculated with and without the "Blank" records. Also, the blank records were apportioned with the same percentages as with the "non-Blank" data. The non-blank data suggest that 26% of the SSO events were contained on site. However, the volume contained on site was 15% to 20%. If it were assumed that the records where the destination is blank tend to be those where no pathway was obvious (e.g., the spill stayed in the yard) then a higher percentage would not get to the bayous.

As shown in Table 7.3, the calculations show that 57% and 61% of SSO excursion volumes in BB and WOB watersheds, respectively, were not assigned a bayou, storm sewer, or drainage ditch destination. From these data, it can be said that most of the 43% and 39% of SSO volumes in BB and WOB, respectively, were likely to reach the bayous, but we can't determine a fraction that did not reach the bayous.

The second approach involves the use of a buffer zone to estimate the potential of an SSO excursion to reach a bayou. This approach involved significant GIS processing. First, the Harris County stream system shapefile called "CAP" and the GIMS storm sewer shapefiles were clipped to the boundaries of the BB and WOB watershed boundaries. Then, a 100-foot buffer zone was created around the CAP centerline, and a 75-foot buffer zone was created around the GIMS storm sewer centerline. The created 100-foot CAP and 75-foot storm sewer buffer zones were then merged into one shapefile. This shapefile was then overlapped with the SSO excursion manhole locations to identify manholes inside and outside of the buffer zones. Figure 7.2 shows an example of the created buffer zones and SSO manhole locations.

Figure 7.2

Example Buffer Zones and SSO Manhole Locations

Table 7.4 lists the results of calculations using the second approach. The results show that about 36% and 33% of SSO excursions in BB and WOB, respectively, are within the buffer zones. In terms of volumes, 36% and 27% of SSOs in BB and WOB, respectively, are within the buffer zones. The percentages were calculated using the adjusted total volumes listed in Table 7.4. The adjustment was made by assigning those SSO excursions without a volume to BB and WOB based on the 18.6% for BB and 17.0% for WOB ratios and the 2,729 gallons per excursion number. This method suggests that something on the order of half of the SSO volumes are within a reasonable distance of a conveyance that might get the flow to a bayou, while the other half of the volume is fairly far removed. Clearly, nothing definitive can be based on a buffer zone analysis, but it does suggest that about half of SSO flows would have a substantial opportunity to soak into the ground or evaporate before reaching a bayou.

7.3 WET WEATHER FACILITY DATA ANALYSIS

One of the tasks is to review TCEQ and City of Houston data to quantify the wastewater input to the bayous via bypasses and overflows. A related situation is discharges from wet weather facilities (WWF) that can be considered as somewhere between a bypass and an overflow. Houston has three WWFs — Northside in the Buffalo Bayou watershed, Belmont in the Brays Bayou watershed, and Bretshire in the Halls Bayou watershed. The Northside WWF is downstream of the study area and the other two are in different watersheds. However the data are compiled, presented and discussed in this section.

WWFs are surge tankage facilities in the sanitary sewer system that act to moderate wastewater flow peaks in much the same way as stormwater detention basins function in the storm sewer infrastructure. If the surge tankage capacity is not exceeded, the tank volume is

Table 7.4
Potential of SSO To Reach Bayous Based on Buffer Zones

Categories	Data Period		Manholes With SSO	No. Excursions			SSO Vol (gal)			
	From	To		Total	w/ Vol	%	Total	Per SSO	Adj Total	%
Entire Database	1/1/2000	12/31/2003	4,282	6,184	6,160		16,811,455	2,729	16,876,954	
Within BB	1/2/2000	12/30/2003	797	1,180	1,173		2,664,502	2,272	3,155,877	
Within BB Buffer			466	662	658	35.9	1,731,976	2,632	1,742,505	35.6
Within WOB	1/4/2000	12/18/2003	730	1,078	1,071		1,937,854	1,809	2,386,960	
Within WOB Buffer			339	522	520	32.7	889,109	1,710	892,529	27.2

returned to the sewer after the flow subsides. If the capacity is exceeded, the excess is discharged after settling and disinfection.

When these facilities were permitted by the TCEQ and the US EPA in the mid-1990s, the permit requirements were that the discharges be monitored and that the receiving bayou be monitored both upstream and downstream of the discharge. The City monitors the discharges with its own staff and has contracted with the USGS to perform bayou monitoring. All the data for this analysis were provided by the City of Houston.

Tables 7.5 to 7.7 show the data for the three WWFs from 1998 to 2004. Tables 7.8 to 7.10 show the bayou monitoring data upstream and downstream of the WWFs during discharge events. A comparison between the data collected upstream and downstream of a WWF will indicate the effect of the discharge on the bayou water quality. Note that some discharge events have no corresponding bayou monitoring data. The averaged values of the parameters are summarized in Tables 7.11 to 7.13. Metals are also shown in Tables 7.8 to 7.10. The metal levels are low with many non-detects and are not considered further in this analysis.

A review of the data in Tables 7.5 to 7.10 and their averages in Tables 7.11 to 7.13 indicates that pH, DO, and TSS in the WWF discharge are generally lower than the values in the bayou, while CBOD, NH3-N, and FC are substantially higher. In all bayou samples, there is no detection of chlorine residuals. The FC levels in the Belmont WWF discharge are usually very high. However, there are also some data with very low values, resulting in a geometric mean lower than those of the bayou.

The WWF discharge rate is generally about two orders of magnitude smaller than the flow rate in the bayou. Therefore, the WWF discharge is not expected to have a substantial impact on the bayou water quality. To check this hypothesis, a statistical test was performed to determine whether there is a significant difference between the average values of pH, DO, CBOD, FC, TSS, and NH3-N at the upstream and downstream sampling locations. With FC, the log data were used in the comparison. The paired data approach discussed in Barnes (1988) was used.

Almost in all cases, it was not possible to prove that the upstream and downstream averages were statistically different. One exception is that the NH3-N level downstream of the Northside WWF was found to be significantly higher than that upstream. One possible explanation is that the samples at the downstream location were affected by the discharge from the 69th Street Plant. Another set of downstream sampling data is available at Lockwood St. This data set is smaller and the sampling location is near the WWF so that complete mixing might not have occurred. Nevertheless, using this data set, there is no significant difference between the upstream and downstream mean for all the parameters. The results are shown in Table 7.14.

Discharges from WWFs occur during storm events when flows in the bayous are high. The above analysis presents the possibility that since the WWF discharge is very small compared with the flow in the bayou, it does not have a significant impact on the water quality in the bayou. Another potential explanation is that the events may need to be examined from an overall loading perspective. The data analysis conducted does not take into account the length of time that the WWFs were discharging and thus if the total load discharged was included in this analysis, the results may reflect more of an impact.

TABLE 7.5
NORTHSIDE WET WEATHER FACILITY DATA

DATE	SAMPLE TYPE	CBOD	TSS	NH3-N	TKN	FECAL COLIFORM	FLOW	pH	D.O.	Cl_2
		MG/L	MG/L	MG/L	MG/L	#/100ML	CFS		MG/L	MG/L
3/16/1998	GRAB	N/A	N/A	N/A	N/A	0		N/A	N/A	1.2
	COMPOSITE	11	91	4.3			0.00			
9/11/1998	GRAB	27	40	6.4	41.2	570,000		7.6	5.7	0.9
	COMPOSITE	21	50	4.2	5.4		122.55			
9/12/1998	GRAB	16	42	1.2	15.4	120,000		7.2	7.6	0.3
	COMPOSITE	18	82	4.8	7.7		83.87			
10/18/1998	GRAB	34	92	5.5	11.4	380,000		7.2	5.3	0.3
	COMPOSITE	30	53	2.9	8.7		152.10			
11/12/1998	GRAB	72	97	12.3	16.5	1,800,000		7	6	0.4
	COMPOSITE	30	58	2.7	5.4		263.05			
11/13/1998	GRAB	46	87	3.4	7.2	350		7.2	6.2	0.9
	COMPOSITE	35	63	2.9	14.7		250.20			
12/11/1998	GRAB	85	138	10.0	12.0	180,000		7.2	6.2	0.04
	COMPOSITE	33	72	2.8	7.9		216.78			
1/2/1999	GRAB	34	81	4.5	9.3	220,000		7.4	6	0.5
	COMPOSITE	38.6	72	4.0	8.6		91.94			
3/13/1999	GRAB	78	80	7.2		2,900,000		7.2	6.4	0.2
	COMPOSITE	51	108	5.3			20.98			
3/19/1999	GRAB	59	109	9.7		120,000		7.7	6	0.4
	COMPOSITE	69	92	6.6			33.89			
5/12/1999	GRAB	39.5	139	6.5		3,400,000		7.5	6.2	0.3
	COMPOSITE	31	126	4.9			99.03			
6/13/1999	GRAB	43.1	66	5.0		3,900,000		7.6	6	0.2
	COMPOSITE	44.9	83	4.8			26.49			
4/2/2000	GRAB	68	65	8.9		1,400,000		7	6.3	0.7
	COMPOSITE	37	49	6.4			49.82			
4/3/2000	GRAB	18	41	2.8		2,100,000		7.2	6.2	0.5
	COMPOSITE	33	45	4.2			43.67			
4/12/2000	GRAB	43	79	7.7		1,100,000		7.1	6.2	0.08
	COMPOSITE	44	65	6.7			40.99			
11/6/2000	GRAB	37	71	4.8		3,500,000		7	6	0.7
	COMPOSITE	29	60	4.0			2.57			
11/24/2000	GRAB	33	68	2.7		9		7	6.5	2.5
	COMPOSITE	45	49	2.5			88.71			
1/11/2001	GRAB	27	114	6.6		1,200,000		7.3	7.6	1.06
	COMPOSITE	65	103	6.6			90.21			
3/28/2001	GRAB	41	117	2.0		450,000		7.7	8.2	0.9
	COMPOSITE	28	65	2.3			174.85			
6/6/2001	GRAB	181	81	1.0		130,000		7.5	7.7	1
	COMPOSITE	16	65	1.1			39.33			
6/9/2001	GRAB	20	77	1.3		3,900,000		7.6	5.4	0.5
	COMPOSITE	11	34	0.7			132.03			
6/10/2001	GRAB	14	27	1.5		4,100,000		8	5.8	0.6
	COMPOSITE	16.4	31	2.0			49.76			
12/12/2001	GRAB	37	112	3.9		2,200,000		6.7	7	0.7
	COMPOSITE	23	63	2.5			92.47			
4/8/2002	GRAB	21	71	2.3		600,000		7.4	7.8	0.4
	COMPOSITE	26	54	2.1			21.63			
8/15/2002	GRAB	29	51	3.3		3,000,000		7.4	5.9	1
	COMPOSITE	18	43	3.2			22.61			
9/20/2002	GRAB	21	113	4.9		3,300,000		6.8	7.2	0.07
	COMPOSITE	23	74	3.9			77.99			
12/12/2002	GRAB	53	90.3	4.0		90		7.4	7.8	1.11
	COMPOSITE	47.5	43	3.7			27.14			
2/21/2003	GRAB	48	73	6.4		12,000,000		7.3	6.6	0.08
	COMPOSITE	35	84	5.6			115.63			
11/17/2003	GRAB	20	72	2.0		1,200,000		7.1	7	0.09
	COMPOSITE	17	49	1.8			106.46			
5/1/2004	GRAB	23.7	56	3.1		400,000		6.8	7	0.09
	COMPOSITE	24.0	54	3.8			95.56			

Source: City of Houston

TABLE 7.6
BELMONT WET WEATHER FACILITY DATA

DATE	SAMPLE TYPE	CBOD	TSS	NH3-N	TKN	FECAL COLIFORM	FLOW	pH	D.O.	Cl_2
		MG/L	MG/L	MG/L	MG/L	#/100ML	CFS		MG/L	MG/L
3/16/1998	GRAB	39	213	1.9		0		7.6	8.5	5.2
	COMPOSITE	54	125	1.0			0.76			
9/11/1998	GRAB	35	60	5.1	38.2	350,000		7.0	7.4	2.0
	COMPOSITE	32	138	3.6	5.4		40.98			
9/12/1998	GRAB	24	14	1.2	4.8	350,000		7.1	7.9	2.5
	COMPOSITE	15	36	3.0	6.1		20.80			
10/18/1998	GRAB	55	95	4.3	10.2	0		7.2	4.9	3.0
	COMPOSITE	24	40	0.9	5.0		26.82			
11/12/1998	GRAB	68	137	4.3	12.0	27		7.2	5.4	3.0
	COMPOSITE	53	58	1.6	5.4		35.31			
11/14/1998	GRAB	55	21	1.5	6.6	36		7.2	5.2	3.0
	COMPOSITE	42	35	0.8	10.6		30.33			
12/11/1998	GRAB	62	107	3.8	6.12	180,000		7.2	7.7	1.7
	COMPOSITE	57	91	1.6	6.54		39.89			
5/12/1999	GRAB	57	124	3.7		250		7.2	3.9	0.0
	COMPOSITE	69	87	2.5	7.6		18.88			
3/15/2000	GRAB	40	72	0.9	7.9	570,000		7.2	4.6	3.2
	COMPOSITE	56	87	0.9	7.3		4.47			
4/2/2000	GRAB	25	52	2.5		230,000		7.2	7.0	<0.1
	COMPOSITE	13	28	1.4	4.8		23.43			
5/2/2000	GRAB	43	91	6.5		420		7.5	5.7	0.8
	COMPOSITE	31	36	3.4	3.5		2.82			
11/12/2000	GRAB	36	111	3.3	7.9	13,000		7.5	8.9	1.7
	COMPOSITE	25	60	1.7	4.4		11.85			
11/18/2000	GRAB	26	44	1.8	5.1	95,000		7.6	7.9	1.2
	COMPOSITE	19	26	0.6	3.4		41.23			
11/19/2000	GRAB	15	23	0.2	2.2	9		7.7	9.9	2.2
	COMPOSITE	12	22	0.1	1.9		1.04			
11/24/2000	GRAB	22	73	1.6	3.8	9		7.5	6.3	2.2
	COMPOSITE	14	44	0.6	2.9		10.94			
1/11/2001	GRAB	44	67	2.8	2.2	27		8.0	7.3	2.2
	COMPOSITE	38	66	3.0	7.6		3.82			
3/28/2001	GRAB	28	125	1.6	5.0	13,000		7.5	6.8	1.6
	COMPOSITE	15	49	1.1	3.2		37.68			
6/5/2001	GRAB	28	103	2.0	3.4	64,000		7.4	6.8	1.1
	COMPOSITE	16	61	0.7	3.5		2.82			
6/7/2001	GRAB	16	47	0.6	3.3	9		7.2	7.5	1.7
	COMPOSITE	11	29	0.5			11.85			
6/8/2001	GRAB	19	99	2.0	2.1	120,000		7.2	8.1	1.1
	COMPOSITE	14	74	0.7	3.3		130.70			
6/9/2001	GRAB	10	18	0.2	3.3	170		7.2	8.1	3.3
	COMPOSITE	62	16	0.2	2.2		1.02			
8/31/2001	GRAB	17	41	1.8	4.2	7,200		7.7	6.6	1.2
	COMPOSITE	17	20	1.6	3.3		12.69			
9/1/2001	GRAB	17	41	0.9	2.6	2,400		7.6	7.1	1.1
	COMPOSITE	16	20	0.8	3.3		16.11			
10/13/2001	GRAB	24	49	1.9	4.9	28		7.1	6.5	1.6
	COMPOSITE	13	33	1.5	3.2		8.88			
12/12/2001	GRAB	36	84	1.7	3.4	1,100		7.2	4.3	3.0
	COMPOSITE	27	65	1.3	3.5		21.75			
12/17/2001	GRAB	30	62	1.3	3.3	9		6.8	5.4	3.3
	COMPOSITE	32	68	1.3	4.9		1.98			
4/8/2002	GRAB	20	65	1.4	3.4	3,900		7.4	6.7	1.2
	COMPOSITE	21	32	3.0	3.8		17.98			
7/13/2002	GRAB	17	68	1.6	4.3	780,000		7.6	6.9	1.6
	COMPOSITE	21	45	1.1	3.4		7.07			
7/16/2002	GRAB	13	25	0.7	3.4	9		7.5	7.1	1.6
	COMPOSITE	15	26	0.5	2.9		0.70			
8/15/2002	GRAB	42	72	2.5	6.7	98,000		7.4	6.9	1.4
	COMPOSITE	18	39	0.6			56.56			
9/20/2002	GRAB	27	60	3.0	6.9	2,000,000		7.3	6.1	1.1
	COMPOSITE	17	97	2.5	5.5		13.36			
10/24/2002	GRAB	45	85	4.7	9.2	1,300,000		7.2	5.1	1.5
	COMPOSITE	34	65	2.5	6.4		14.76			
10/27/2002	GRAB	29	79	1.9	5.8	260,000		7.6	7.1	1.1
	COMPOSITE	27	46	1.3	4.1		2.39			
10/28/2002	GRAB	33	38	1.7	5.0	130		7.4	7.3	1.1
	COMPOSITE	28	35	1.4	4.5		10.48			
11/4/2002	GRAB	18	29	1.2	3.0	92		7.5	7.6	1.5
	COMPOSITE	19	26	1.2	2.9		2.77			
12/12/2002	GRAB	68	85	5.0	10.4	1,100		7.3	7.4	1.1
	COMPOSITE	55	67	3.7	9.1		3.81			
2/21/2003	GRAB	59	109	6.0	9.9	260,000		7.2	5.3	1.6
	COMPOSITE	28	70	2.5	4.8		20.46			
9/21/2003	GRAB	21	55	2.9	5.8	390,000		6.9	6.3	1.3
	COMPOSITE	16	42	2.6	5.2		3.07			
10/9/2003	GRAB	36	88	1.2	7.3	310,000		7.2	5.9	1.0
	COMPOSITE	40	78	2.9	6.9		3.76			
11/17/2003	GRAB	37	88	3.6	6.6	16,000		7.1	5.8	1.5
	COMPOSITE	38	51	1.6	4.2		20.00			
12/13/2003	GRAB	25	69	4.1	7.9	100,000		7.1	6.9	1.4
	COMPOSITE	25	63	3.4	6.9		1.79			
1/17/2004	GRAB	30	100	4.0	8.2	15,000		7.3	6.6	1.3
	COMPOSITE	37	96	3.3	7.6		3.90			
1/25/2004	GRAB	65	98	2.6	7.4	140,000		6.9	7.2	1.4
	COMPOSITE	58	54	2.4	2.4		5.03			
2/5/2004	GRAB	49	76	2.3	6.7	<9		7.8	6.5	2.2
	COMPOSITE	43	48	1.8	5.4		0.36			
2/10/2004	GRAB	36	48	1.3	3.9	<9		7.0	6.4	2.2
	COMPOSITE	27	38	0.8	2.9		11.47			
5/1/2004	GRAB	50	104	4.0	5.1	64,000		6.9	7.0	1.2
	COMPOSITE	32	82	4.1	5.8		21.76			
5/11/2004	GRAB	50	74	2.7	5.3	230,000		7.1	7.0	1.3
	COMPOSITE	47	66	2.6	2.4		4.98			
5/13/2004	GRAB	45	128	1.8	6.5	2,700,000		7.2	7.6	1.4
	COMPOSITE	19	42	0.5	3.4		37.35			
6/25/2004	GRAB	15	78	0.9	2.8	9		7.2	7.5	1.9
	COMPOSITE	10	39	0.6	2.7		9.56			

Source: City of Houston

TABLE 7.7
BRETSHIRE WET WEATHER FACILITY DATA

DATE	SAMPLE TYPE	CBOD	TSS	NH3-N	TKN	FECAL COLIFORM	FLOW	pH	D.O.	Cl_2
		MG/L	MG/L	MG/L	MG/L	#/100ML	CFS		MG/L	MG/L
9/11/1998	GRAB	20	125	2.4	23.1	24,000		7.1	6.4	0.1
	COMPOSITE	18	55	1.4	4.2		11.84			
10/18/1998	GRAB	39	94	4.0	9.0	470,000		7.2	6.2	0.1
	COMPOSITE	34	79	2.8	8.3		7.26			
11/12/1998	GRAB	34	75	2.9	5.7	990,000				
	COMPOSITE	17	52	1.8	3.9		3.09	7.2	6.6	0.2
11/14/1998	GRAB	20	23	1.2	4.5	250,000		7.2	3.6	0.1
	COMPOSITE	19	33	1.2	8.76		6.54			
12/11/1998	GRAB	20	70	1.3	2.74	200		7.6	N/A	0.1
	COMPOSITE	25	64	1.6	4.32		9.19			
1/2/1999	GRAB	28	69	2.5	7.4	190,000		7.2	3	0.02
	COMPOSITE	24	70	2.5	6.2		0.55			
5/12/1999	GRAB	20	132	2.4	6.1	2,300,000		7.4	N/A	0.1
	COMPOSITE	27	95	2.3	5.7		7.26			
6/8/2001	GRAB	16	73	1.2			3.71	6.8	1.3	0.5
	COMPOSITE	45	49	2.5		670,000				
4/8/2002	GRAB	29	110	2.7		920,000		7.2	7	0.6
	COMPOSITE	29	54	2.8			1.52			
9/19/2002	GRAB	25	96	1.7		820,000		5	4.1	0.5
	COMPOSITE	23	55	1.5			4.43			
10/28/2002	GRAB	19	56.6	1.1		260,000		7.3	7.1	1.2
	COMPOSITE	15	59.6	0.9			3.96			
7/9/2003	GRAB	21	64	1.3		930,000		7.1	6	1
	COMPOSITE	21	58	1.31			0.64			
11/17/2003	GRAB	24	58	1.0		1,900,000		7.6	5.8	0.5
	COMPOSITE	24	52	0.8			0.02			
5/1/2004	GRAB	20.0	62	0.9		760		7	7	0.06
	COMPOSITE	19.3	54	2.8			3.05			
5/13/2004	GRAB	24.5	58	1.4		230,000		6.8	7.57	0
	COMPOSITE	11.0	36	0.9			5.65			
6/24/2004	GRAB	9.3	67	1		690,000		7.2	6.8	0.7
	COMPOSITE	8.6	55	1.1			4.24			
6/25/2004	GRAB	11.0	37	1.3		8,000,000		7.5	6.5	0.5
	COMPOSITE	11.0	37	1.4			1.40			

Source: City of Houston

TABLE 7.8
MONITORING DATA OF BUFFALO BAYOU UPSTREAM AND DOWNSTREAM OF NORTHSIDE WET WEATHER FACILITY

Date	Time	Location	Flow (cfs)	pH	Dis. Oxy. (mg/l)	5-day BOD (mg/l)	CBOD (mg/l)	Cl_2 (mg/l)	Fecal Coliform (# per 100 ml)	TSS (mg/l)	NH_3-N (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Pb (mg/l)	Hg (mg/l)	Ni (mg/l)	Ag (mg/l)	Zn (mg/l)
3/16/98	6:33 PM	Hirsch St	3,200	7.4	7.8	8.4	7.0	ND	16,000	62	0.140	<0.004	0.006	0.009	<0.03	<0.0002	<0.023	<0.004	0.0520
	7:02 PM	69th St Plant	3,200	8.0	5.8	5.5	4.5	ND	26,000	110	0.180	<0.004	0.007	0.011	<0.03	<0.0002	<0.023	<0.004	0.0990
9/11/98	12:35 PM	Hirsch St	34,000	7.9	7.1	2.8	1.7	ND	31,000	370	0.130	<0.001	<0.005	0.011	0.0380	<0.0002	<0.01	<0.002	0.1200
	12:50 PM	Lockwood St	34,000	7.9	8.0	2.5	1.3	ND	26,000	570	0.060	<0.001	<0.005	0.019	0.0630	<0.0002	<0.01	<0.002	0.1400
9/12/98	3:15 PM	Hirsch St	4,300	6.1	6.0	2.1	1.1	ND	29,000	140	0.060	<0.001	<0.005	<0.01	0.0095	<0.0002	<0.01	<0.002	0.0590
	2:45 PM	69th St Plant	4,300	6.3	5.8	3.1	1.6	ND	32,000	160	0.050	<0.001	<0.005	<0.01	0.0083	<0.0002	<0.01	<0.002	0.0470
10/18/98	5:19 PM	Hirsch St	10,800	7.5	7.2	5.1	2.7	ND	36,000	380	0.130	<0.001	<0.005	0.010	0.0200	<0.0002	<0.01	<0.002	0.0770
	5:00 PM	69th St Plant	10,800	7.4	7.6	6.2	3.3	ND	39,000	470	0.240	<0.001	<0.005	0.010	0.0350	<0.0002	<0.01	<0.002	0.1200
11/12/98	10:30 PM	Hirsch St	12,000	7.8	7.6	4.8	4.3	ND	29,000	390	0.150	<0.001	<0.005	<0.01	0.0200	<0.0002	<0.01	<0.002	0.0930
	10:15 PM	Lockwood St	12,000	7.9	7.7	6.7	5.1	ND	34,000	380	0.230	<0.001	<0.005	<0.01	0.0220	<0.0002	<0.01	<0.002	0.0860
	9:50 PM	69th St Plant	12,000	7.9	8.6	8.2	3.7	ND	14,000	670	0.330	<0.001	<0.005	0.016	0.0350	<0.0002	<0.01	<0.002	0.1370
11/13/98	8:01 PM	Hirsch St	7,920	7.1	6.6	3.6	3.2	ND	26,000	150	0.090	<0.001	<0.005	<0.01	0.0150	<0.0002	<0.01	<0.002	0.0580
	7:46 PM	Lockwood St	7,920	7.1	7.4	7.7	7.2	ND	36,000	120	0.340	<0.001	<0.005	<0.01	0.0087	<0.0002	<0.01	<0.002	0.0480
	7:22 PM	69th St Plant	7,920	7.0	6.8	5.4	2.3	ND	15,000	170	0.220	<0.001	<0.005	<0.01	0.0089	<0.0002	<0.01	<0.002	0.0390
12/11/98	3:50 PM	Hirsch St	8,100	7.8	10.3	6.0	5.0	ND	34,000	330	0.340	<0.001	<0.005	<0.01	0.0180	<0.0002	<0.01	<0.002	0.0805
	4:20 PM	Lockwood St	8,100	7.7	10.3	7.2	5.7	ND	29,000	240	0.380	<0.001	<0.005	<0.01	0.0180	<0.0002	<0.01	<0.002	0.0873
	4:10 PM	69th St Plant								320	0.310	<0.001	<0.005	<0.01	0.0260	<0.0002	<0.01	<0.002	0.0980
3/19/99	1:42 PM	Hirsch St	11,400	7.8	6.6	8.8	8.2	ND	25,000	238	0.760	<0.001	<0.005	0.022	0.0210	<0.0002	<0.01	<0.002	0.1250
	1:24 PM	Lockwood St	11,400	7.6	7.6	8.8	8.5	ND	18,000	312	0.560	<0.001	<0.005	0.021	0.0260	<0.0002	0.010	<0.002	0.1320
	1:01 PM	69th St Plant	11,400	7.4	7.9	9.0	7.5	ND	29,000	534	1.390	<0.001	0.024	0.039	0.0730	<0.0002	0.020	<0.002	0.2790
5/12/99	2:10 PM	Hirsch St	7,470	8.2	9.5	7.0	5.6	ND	25,000	253	0.250	<0.001	<0.01	0.026	0.0180	<0.0002	0.010	<0.002	0.1070
	2:20 PM	Lockwood St	7,470	8.1	8.0	6.7	4.9	ND	34,000	314	0.370	<0.001	0.021	0.026	0.0230	<0.0002	<0.01	<0.002	0.1340
	2:40 PM	69th St Plant	7,470	8.0	7.8	7.9	6.0	ND	38,000	554	0.490	<0.001	0.023	0.043	0.0430	<0.0002	0.013	<0.002	0.2260
6/13/99	5:50 PM	Hirsch St	3,390	7.6	6.2	7.7	6.6	ND	29,000	135.5	<0.10	<0.001	<0.005	0.023	0.0180	<0.0002	<0.01	<0.002	0.1030
	6:50 PM	Lockwood St	3,390	7.8	6.1	6.7	6.4	ND	39,000	98.4	<0.10	<0.001	<0.005	0.021	0.0110	<0.0002	<0.01	<0.002	0.0650
	5:27 PM	69th St Plant	3,390	7.5	5.7	7.2	7.0	ND	34,000	31.2	0.360	<0.001	<0.005	0.019	0.0140	<0.0002	<0.01	<0.002	0.1110
4/2/00	10:00 AM	Hirsch St	6,400	7.2	7.2	8.7	8.5	ND	32,000	945	0.690	<0.001	<0.005	<0.01	0.0380	<0.0002	<0.01	<0.002	0.2260
	10:25 AM	Lockwood St	6,400	8.1	6.9	8.4	8.2	ND	29,000	790	0.810	0.001	<0.005	<0.01	0.0430	<0.0002	<0.01	<0.002	0.2640
	10:35 AM	69th St Plant	6,400	7.8	5.9	8.7	8.6	ND	28,000	1030	0.960	0.001	<0.005	0.017	0.0630	<0.0002	<0.01	<0.002	0.3510
4/3/00	12:00 PM	Hirsch St	4,180	7.7	8.2	6.1	5.3	ND	30,000	113	0.320	<0.001	<0.005	<0.01	0.0070	<0.0002	<0.01	<0.002	0.0420
	12:25 PM	69th St Plant	4,180	7.2	8.4	8.0	6.9	ND	29,000	157	0.380	<0.001	<0.005	<0.01	0.0130	<0.0002	<0.01	<0.002	0.0800
4/12/00	3:05 PM	Hirsch St	5,050	7.8	8.0	7.5	5.9	ND	29,000	254	0.300	<0.001	<0.005	<0.01	0.0110	<0.0002	<0.01	<0.002	0.0930
	2:35 PM	69th St Plant	5,050	7.8	7.8	8.3	7.8	ND	32,000	260	0.510	<0.001	0.007	0.013	0.0170	<0.0002	<0.01	<0.002	0.1460
11/6/00	7:45 AM	Hirsch St	5,680	7.7	6.0	5.1	3.6	ND	25,000	374	0.810	<0.001	<0.005	0.01	0.0610	<0.0002	<0.01	<0.002	0.1660
	8:10 AM	69th St Plant	5,680	7.6	7.2	6.4	4.3	ND	28,000	352	0.870	<0.001	<0.005	<0.01	0.0210	<0.0002	<0.01	<0.002	0.1380
1/11/01	12:45 PM	Hirsch St	4,300	7.8	10.2	8.5	5.7	ND	14,000	254	0.230	<0.001	<0.005	0.013	0.0170	<0.0002	<0.01	<0.002	0.1370
	1:03 PM	69th St Plant	4,400	7.7	10.2	8.5	5.6	ND	20,000	64	0.280	<0.001	<0.005	0.013	0.0360	<0.0002	<0.01	<0.002	0.0930
3/28/01	12:39 AM	Hirsch St	11,200	7.9	6.7	8.8	8.0	ND	10,000	392	0.560	0.003	<0.005	<0.01	0.0050	<0.0002	<0.01	<0.002	0.4070
6/6/01	7:30 AM	Hirsch St	6,830	7.9	5.3	4.5	3.4	ND	11,000	194	0.160	<0.001	<0.005	<0.01	0.0100	<0.0002	<0.01	<0.002	0.0500
	7:45 AM	Lockwood St	6,830	7.7	6.2	4.8	3.5	ND	16,000	204	0.240	<0.001	<0.005	0.01	0.0080	<0.0002	<0.01	<0.002	0.0400
	8:10 AM	69th St Plant	6,830	7.5	6.6	3.8	3.7	ND	30,000	150	0.740	<0.001	<0.005	<0.01	0.0110	<0.0002	<0.01	<0.002	0.0460
12/12/01	4:25 AM	Hirsch St	12,400	8.1	7.7	6.6	5.0	ND	36,000	813	<0.10	<0.001	<0.005	0.011	0.0370	<0.0002	<0.01	<0.002	0.1300
	4:48 AM	69th St Plant	12,400	8.0	7.5	6.9	5.3	ND	34,000	790	0.130	<0.001	<0.005	0.013	0.0460	<0.0002	<0.01	<0.002	0.1780
4/8/02	10:33 AM	Hirsch St								516	0.420	<0.001	<0.005	0.019	0.0240	<0.0002	<0.01	<0.002	0.1230
	10:05 AM	69th St Plant								764	0.550	<0.001	<0.005	0.024	0.0360	<0.0002	<0.01	<0.002	0.1900
8/15/02	9:30 PM	Hirsch St	4,400	7.8	6.2	4.1	2.2	ND	38,000	293	<0.10	<0.001	<0.005	<0.01	0.0110	<0.0002	<0.01	<0.002	0.0460
	10:45 PM	69th St Plant	4,400	7.8	8.1	5.2	2.6	ND	42,000	360	<0.10	<0.001	<0.005	<0.01	0.0160	<0.0002	<0.01	<0.002	0.0790
9/19/02	11:50 PM	Lockwood St	5,700	7.6	7.5	7.5	6.3	ND	120,000	212	<0.10	<0.001	<0.005	<0.01	0.0100	<0.0002	<0.01	<0.002	0.0690
	11:30 PM	69th St Plant	5,700	7.8	7.0	7.7	6.9	ND	75,000	391	<0.10	<0.001	<0.005	<0.01	0.0280	<0.0002	<0.01	<0.002	0.1160
9/20/02	12:13 AM	Hirsch St	5,700	8.0	7.1	7.1	6.6	ND	72,000	315	<0.10	<0.001	<0.005	<0.01	0.0170	<0.0002	<0.01	<0.002	0.0750
2/21/03	4:40 AM	69th St Plant	3,350	7.6	7.9	8.6	6.3	ND	40,000	350	0.27	<0.001	<0.005	<0.01	0.011	<0.0002	<0.01	<0.002	0.044
	5:05 AM	Hirsch St	3,350	7.6	8.6	5.6	3.8	ND	14,000	184	<0.01	<0.001	<0.005	<0.01	0.014	<0.0002	<0.01	<0.002	0.070
11/17/03	8:04PM	Hirsch St	15,200	7.9	7.7	4.7	3.3	ND	44,000	1054	<0.01	<0.001	<0.005	0.030	0.098	<0.0002	<0.01	<0.002	0.302
	8:30 PM	69th St Plant	15,200	8.1	7.2	5.4	2.4	ND	49,000	1422	0.31	<0.001	<0.005	0.025	0.079	<0.0002	<0.01	<0.002	0.214
5/1/04	7:10 PM	Hirsch St	8,800	7.3	7.5	5.3	4.1	ND	39,000	336	0.17	<0.001	<0.005	<0.01	0.014	<0.0002	<0.01	<0.002	0.064
	7:25 PM	69th St Plant	8,800	7.2	7.3	4.2	3.7	ND	36,000	340	0.28	<0.001	<0.005	<0.01	0.016	<0.0002	<0.01	<0.002	0.084

Source: City of Houston

ND = Non-detection

Hirsch St - Upstream Sampling Point
69th St Plant, Lockwood St - Downstream Sampling Points

TABLE 7.9
MONITORING DATA OF BRAYS BAYOU UPSTREAM AND DOWNSTREAM OF BELMONT WET WEATHER FACILITY

Date	Time	Location	Flow (cfs)	pH	Dis. Oxy. (mg/l)	5-day BOD (mg/l)	CBOD (mg/l)	Cl_2 (mg/l)	Fecal Coliform (# per 100 ml)	TSS (mg/l)	NH_3-N (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Pb (mg/l)	Hg (mg/l)	Ni (mg/l)	Ag (mg/l)	Zn (mg/l)
3/16/98	2:50 PM	CALHOUN	4,500	7.2	8.4		5.3	ND	15,000	160	0.37	<0.004	0.008	0.012	<0.030	<0.0002	<0.023	<0.004	0.0900
	2:28 PM	LIDSTONE	4,500	7.5	8.6		5.0	ND	31,000	180	0.29	<0.004	0.008	0.012	<0.030	<0.0002	<0.023	<0.004	0.1040
9/11/98	2:10 PM	CALHOUN	17,400	7.6	6.9		1.4	ND	42,000	210	0.07	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0330
	1:40 PM	LIDSTONE	18,300	7.7	7.0		1.7	ND	36,000	360	0.07	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0390
9/12/98	1:55 PM	CALHOUN	1,650	7.5	7.4		1.6	ND	48,000	86	0.15	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0430
	2:25 PM	LIDSTONE	1,510	6.7	6.9		1.9	ND	34,000	85	0.18	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0390
10/18/98	4:15 PM	CALHOUN	10,000	7.3	8.4		2.3	ND	48,000	59	0.10	<0.001	<0.005	<0.010	0.0053	<0.0002	<0.010	<0.002	0.0290
	4:32 PM	LIDSTONE	10,000	7.3	8.4		2.8	ND	39,000	680	0.30	<0.001	<0.005	0.010	0.0200	<0.0002	<0.010	<0.002	0.0790
11/12/98	11:50 PM	CALHOUN	9,300	7.6	9.5		2.4	ND	26,000	130	0.25	<0.001	<0.005	<0.010	0.0060	<0.0002	<0.010	<0.002	0.0499
11/13/98	12:02 AM	LIDSTONE	9,300	7.7	10.1		3.4	ND	12,000	150	0.31	<0.001	<0.005	<0.010	0.0061	<0.0002	<0.010	<0.002	0.0468
11/14/98	11:39 AM	CALHOUN	8,800	7.4	10.9		1.1	ND	15,000	88	0.10	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0300
	11:56 AM	LIDSTONE	8,800	7.4	10.8		0.5	ND	17,000	84	0.13	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0209
12/11/98	3:10 PM	CALHOUN	9,100	7.9	10.8		3.5	ND	32,000	170	0.28	<0.001	<0.005	<0.010	0.0064	<0.0002	<0.010	<0.002	0.0399
	3:30 PM	LIDSTONE	8,840	7.9	10.9		4.2	ND	36,000	180	0.37	<0.001	<0.005	<0.010	0.0076	<0.0002	<0.010	<0.002	0.0430
5/12/99	3:40 PM	CALHOUN	10,000	8.4	9.5		3.4	ND	31,000	153	0.32	<0.001	0.018	23.000	0.0070	<0.0002	<0.010	<0.002	0.0780
	3:10 PM	LIDSTONE	10,500	8.5	8.5		5.9	ND	28,000	195	0.51	<0.001	<0.005	26.000	0.0080	<0.0002	<0.010	<0.002	0.0830
3/15/00	10:56 PM	CALHOUN	412	8.1	7.1		6.7	ND	5,100	94.7	0.52	<0.001	<0.005	12.000	0.0100	<0.0002	<0.010	<0.002	0.0620
	11:30 PM	LIDSTONE	400	8.3	6.9		6.0	ND	7,700	83	0.35	<0.001	<0.005	<0.010	0.0100	<0.0002	<0.010	<0.002	0.0460
4/2/00	11:30 PM	CALHOUN	1,150	8.1	9.5		6.1	ND	25,000	66	1.42	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0400
4/3/00	12:20 AM	LIDSTONE	1,150	7.8	7.4		6.0	ND	16,000	55	1.50	<0.001	<0.005	<0.010	<0.005	<0.0002	<0.010	<0.002	0.0440
5/2/00	9:42 AM	Calhoun St	5,100	7.7	8.6	7.8	6.5	ND	30,000	117	0.69	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0580
	10:14 AM	Lidstone St	5,100	7.5	8.4	7.4	5.9	ND	25,000	126	0.48	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0600
11/12/00	10:05 PM	Calhoun St	16,000	8.3	8.6	5.7	4.5	ND	18,000	268	1.22	<0.001	<0.005	0.017	0.0230	<0.0002	<0.01	<0.002	0.0890
	10:30 PM	Lidstone St	16,000	8.1	9.1	4.7	3.6	ND	29,000	271	0.62	<0.001	<0.005	0.012	0.0150	<0.0002	<0.01	<0.002	0.0620
11/18/00	8:55 AM	Calhoun St	5,400	7.7	11.1	2.2	1.7	ND	11,000	57	0.22	<0.001	0.006	<0.01	0.0240	<0.0002	<0.01	<0.002	0.1240
11/24/00	7:15 AM	Calhoun St	4,700	8.1	8.6	4.7	3.3	ND	31,000	203	0.71	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0510
	7:31 AM	Lidstone St	4,700	8.1	8.6	4.8	3.6	ND	11,000	211	1.88	<0.001	<0.005	<0.01	0.0080	<0.0002	<0.01	<0.002	0.0770
6/5/01	11:33 PM	Calhoun St	14,600	8.1	7.5	4.3	3.9	ND	8,300	92	0.11	<0.001	<0.005	<0.01	0.0070	<0.0002	<0.01	<0.002	0.0490
	10:50 PM	Lidstone St	14,600	7.6	7.6	4.9	3.9	ND	9,700	116	0.23	<0.001	<0.005	<0.01	0.0080	<0.0002	<0.01	<0.002	0.0520
6/7/01	9:45 AM	Calhoun St	14,400	8.3	8.0	3.9	3.0	ND	26,000	152	0.21	<0.001	<0.005	<0.01	0.0050	<0.0002	<0.01	<0.002	0.0440
	9:15 AM	Lidstone St	14,400	8.1	8.0	3.8	3.5	ND	29,000	160	<0.10	<0.001	<0.005	<0.01	0.0070	<0.0002	<0.01	<0.002	0.0500
6/9/01	11:25 PM	Calhoun St	2,500	7.7	6.3	7.5	5.8	ND	10,000	52	0.60	<0.001	<0.005	<0.01	0.0100	<0.0002	<0.01	<0.002	0.0920
	10:43 PM	Lidstone St	2,500	7.6	6.2	4.3	3.6	ND	11,000	60	0.47	<0.001	<0.005	<0.01	0.0100	<0.0002	<0.01	<0.002	0.4130
8/31/01	11:05 AM	Calhoun St	5,700	7.5	7.3	3.4	2.6	ND	75,000	104	0.55	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0330
	10:45 AM	Lidstone St	5,700	8.7	8.3	3.7	2.9	ND	35,000	238	0.78	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0430
9/1/01	10:53 AM	Calhoun St	4,200	8.5	7.7	2.8	1.7	ND	44,000	60	1.18	<0.001	<0.005	<0.01	0.0070	<0.0002	<0.01	<0.002	0.0530
	10:30 AM	Lidstone St	4,200	7.7	7.8	3.0	2.2	ND	25,000	90	0.40	<0.001	<0.005	<0.01	0.0100	<0.0002	<0.01	<0.002	0.0450
10/13/01	1:40 PM	Calhoun St	5,400	7.6	8.2	3.4	2.8	ND	49,000	131	0.86	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0310
	1:20 PM	Lidstone St	5,400	7.7	8.1	4.8	3.8	ND	60,000	138	1.01	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0390
12/12/01	4:03 AM	Calhoun St	15,000	8.1	8.4	4.9	4.7	ND	29,000	289	0.63	<0.001	<0.005	<0.01	0.0080	<0.0002	<0.01	<0.002	0.0750
	3:29 AM	Lidstone St	15,000	8.0	9.1	5.2	3.9	ND	26,000	247	0.22	<0.001	<0.005	<0.01	0.0110	<0.0002	<0.01	<0.002	0.0710
4/8/02	8:07 AM	Calhoun St	13,200	7.9	8.2	7.2	5.5	ND	26,000	160	0.39	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0470
	9:20 AM	Lidstone St	13,200	7.9	8.2	7.1	5.2	ND	18,000	190	0.38	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0390
7/13/02	11:10 PM	Lidstone St	7,970	7.5	7.2	4.6	2.9	ND	16,000	240	0.20	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0760
7/16/02	11:30 PM	Calhoun St	7,970	7.0	7.1	2.4	2.0	ND	13,000	236	0.23	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0580
	4:09 PM	Lidstone St	1,290	7.7	6.3	3.1	2.1	ND	40,000	77	0.21	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0360
8/15/02	12:25 PM	Calhoun St	15,200	8.0	9.6	4.1	2.8	ND	36,000	136	<0.10	<0.001	<0.005	<0.01	0.0070	<0.0002	<0.01	<0.002	0.0360
	11:45 AM	Lidstone St	15,200	8.0	7.7	3.5	2.8	ND	32,000	158	<0.10	<0.001	<0.005	<0.01	0.0110	<0.0002	<0.01	<0.002	0.0430
10/24/02	8:30 PM	Calhoun St	5,300	7.6	8.2	4.8	3.4	ND	36,000	250	<0.10	<0.001	<0.005	0.060	0.0130	<0.0002	<0.01	<0.002	0.1600
	9:10 PM	Lidstone St	5,300	7.7	8.0	4.6	2.5	ND	30,000	226	<0.10	<0.001	<0.005	0.038	0.0140	<0.0002	<0.01	<0.002	0.1920
10/27/02	8:15 AM	Calhoun St	2,320	7.6	7.9	3.9	2.9	ND	15,000	80	0.27	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0620
	7:55 AM	Lidstone St	2,320	7.6	8.0	3.9	2.4	ND	29,000	80	0.45	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0400
10/28/02	10:30 PM	Calhoun St	11,400	7.7	8.2	5.1	3.8	ND	31,000	319	0.76	<0.001	<0.005	<0.01	0.0100	<0.0002	<0.01	<0.002	0.0690
	11:10 PM	Lidstone St	11,400	7.7	8.0	4.1	2.7	ND	40,000	348	0.75	<0.001	<0.005	<0.01	0.012	<0.0002	<0.01	<0.002	0.072
11/4/02	10:30 AM	Calhoun St	4,500	7.6	9.0	4.8	3.0	ND	11,000	93	0.13	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.023
	10:40 AM	Lidstone St	4,500	7.6	9.0	4.5	2.7	ND	10,000	101	0.12	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.019
2/21/03	3:50 AM	Calhoun St	4,150	7.8	8.8	9.2	6.3	ND	29,000	312	<0.10	<0.001	<0.005	<0.01	0.012	<0.0002	<0.01	<0.002	0.103
	4:15 AM	Lidstone St	4,150	7.8	8.8	8.8	6.0	ND	14,000	326	<0.10	<0.001	<0.005	<0.01	0.010	<0.0002	<0.01	<0.002	0.084
9/21/03	1:53 PM	Calhoun St	4,600	7.6	7.4	4.5	2.5	ND	30,000	115	0.20	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.045
	2:06 PM	Lidstone St	4,600	7.7	7.5	4.1	3.0	ND	41,000	120	0.23	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.040
10/9/03	10:25 PM	Calhoun St	14,500	6.8	8.1	3.4	2.9	ND	17,000	263	0.13	<0.001	<0.005	<0.01	0.006	<0.0002	<0.01	<0.002	0.038
	10:00 PM	Lidstone St	14,500	8.1	7.2	5.2	3.6	ND	26,000	333	0.20	<0.001	<0.005	<0.01	0.006	<0.0002	<0.01	<0.002	0.065
12/13/03	4:50 AM	Calhoun St	2,800	7.7	8.8	8.4	5.0	ND	14,000	243	0.70	<0.001	<0.005	<0.01	0.007	<0.0002	<0.01	<0.002	0.041
	5:26 AM	Lidstone St	2,800	7.9	8.8	8.7	5.8	ND	13,000	278	0.69	<0.001	<0.005	<0.01	0.008	<0.0002	<0.01	<0.002	0.046
1/25/04	8:05 AM	Calhoun St	3,600	7.9	6.3	5.3	3.2	ND	31,000	157	0.49	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.033
	8:25 AM	Lidstone St	3,600	7.9	6.9	4.8	3.4	ND	29,000	151	0.49	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.033
2/5/04	11:00 AM	Calhoun St	1,600	7.8	9.5	8.1	5.1	ND	17,000	63	0.33	<0.001	<0.005	<0.01	0.013	<0.0002	<0.01	<0.002	0.105
	11:40 AM	Lidstone St	1,600	7.8	9.1	7.9	5.4	ND	15,000	17	0.57	<0.001	<0.005	<0.01	0.008	<0.0002	<0.01	<0.002	0.068
2/10/04	10:50 PM	Calhoun St	2,890	7.9	10.0	5.4	4.0	ND	10,000	168	0.30	<0.001	<0.005	<0.01	0.008	<0.0002	<0.01	<0.002	0.061
	11:10 PM	Lidstone St	2,890	7.9	9.4	6.4	4.2	ND	8,300	180	0.32	<0.001	<0.005	<0.01	0.009	<0.0002	<0.01	<0.002	0.066
5/1/04	4:10 PM	Lidstone St	11,000	6.9	8.5	5.1	3.8	ND	38,000	190	0.29	<0.001	<0.005	<0.01	0.011	<0.0002	<0.01	<0.002	0.053
	4:30 PM	Calhoun St	11,000	6.7	8.5	5.0	4.0	ND	34,000	154	0.33	<0.001	<0.005	<0.01	0.006	<0.0002	<0.01	<0.002	0.042
5/11/04	10:30 PM	Lidstone St	4,600	8.2	7.1	6.1	4.7	ND	32,000	180	0.27	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.034
	10:45 PM	Calhoun St	4,500	8.1	7.0	6.1	4.0	ND	28,000	342	0.68	<0.001	<0.005	<0.01	0.006	<0.0002	<0.01	<0.002	0.043
5/13/04	8:10 PM	Lidstone St	5,500	8.7	7.9	6.3	5.1	ND	31,000	162	0.25	<0.001	<0.005	<0.01	0.012	<0.0002	<0.01	<0.002	0.060
	8:24 PM	Calhoun St	5,500	8.0	7.9	5.7	4.5	ND	40,000	117	0.16	<0.001	<0.005	<0.01	0.007	<0.0002	<0.01	<0.002	0.046

Source: City of Houston

Lidstone St - Downstream Sampling Pc ND = Non-detection
Calhoun St - Upstream Sampling Point

TABLE 7.10
MONITORING DATA OF HALLS BAYOU UPSTREAM AND DOWNSTREAM OF BRETSHIRE WET WEATHER FACILITY

Date	Time	Location	Flow (cfs)	pH	Dis. Oxygen (mg/l)	5-day BOD (mg/l)	CBOD (mg/l)	Cl_2 (mg/l)	Fecal Coliform (# per 100 ml)	TSS (mg/l)	NH_3-N (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Pb (mg/l)	Hg (mg/l)	Ni (mg/l)	Ag (mg/l)	Zn (mg/l)
9/11/98	11:55 AM	Allwood St	200	7.3	6.9	1.4	0.6	ND	13,000	160	0.230	<0.001	<0.005	<0.01	0.0110	<0.0002	<0.01	<0.002	0.0900
	11:45 AM	Parker Rd	4,350	7.7	6.4	2.4	1.6	ND	32,000	300	0.240	<0.001	<0.005	<0.01	0.0070	<0.0002	<0.01	<0.002	0.0480
	11:28 AM	Homestead St	4,410	7.6	6.6	2.2	1.6	ND	38,000	310	0.060	<0.001	<0.005	<0.01	0.0097	<0.0002	<0.01	<0.002	0.0530
10/18/98	3:26 PM	Allwood St	100	7.2	7.9	2.8	2.4	ND	20,000	110	0.100	<0.001	0.0068	0.0100	0.0060	<0.0002	<0.01	<0.002	0.0480
	3:17 PM	Parker Rd	1,390	7.5	7.1	5.6	3.6	ND	44,000	480	0.190	<0.001	<0.005	<0.01	0.0150	<0.0002	<0.01	<0.002	0.0650
	3:00 PM	Homestead St	1,390	7.5	7.3	5.9	4.2	ND	49,000	97	0.100	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0370
11/12/98	11:14 PM	Allwood St	90	7.8	9.0	3.2	2.2	ND	20,000	180	0.078	<0.001	<0.005	<0.01	0.0084	<0.0002	<0.01	<0.002	0.0705
	11:05 PM	Parker Rd	1,850	7.7	8.7	4.4	3.6	ND	36,000	310	0.160	<0.001	<0.005	<0.01	0.0080	<0.0002	<0.01	<0.002	0.0480
	10:57 PM	Homestead St	1,850	7.7	7.5	4.4	3.0	ND	20,000	370	0.190	<0.001	<0.005	<0.01	0.0100	0.0002	<0.01	<0.002	0.0500
11/14/98	11:05 AM	Allwood St	80	7.1	10.0	0.9	0.4	ND	13,000	47	0.072	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0347
	10:56 AM	Parker Rd	1,650	7.2	9.8	2.8	1.9	ND	28,000	250	0.110	<0.001	<0.005	<0.01	0.0079	<0.0002	<0.01	<0.002	0.0340
	10:42 AM	Homestead St	1,650	7.3	10.0	2.7	1.5	ND	25,000	330	0.081	<0.001	<0.005	<0.0	0.0082	<0.0002	<0.0	<0.002	0.0410
12/11/98	2:50 PM	Allwood St	90	7.6	10.4	3.7	3.3	ND	19,000	100	0.150	<0.001	<0.005	<0.01	0.0084	<0.0002	<0.01	<0.002	0.0612
	2:40 PM	Parker Rd	1,900	7.6	10.2	5.0	3.7	ND	49,000	460	0.270	<0.001	<0.005	<0.01	<0.005	<0.0002	<0.01	<0.002	0.0684
	2:20 PM	Homestead St	1,970	7.8	10.2	5.4	3.9	ND	39,000	600	0.320	<0.001	<0.005	<0.01	0.0180	<0.0002	<0.01	<0.002	0.0686
5/12/99	1:30 PM	Allwood St	60	7.8	7.7	5.0	2.7	ND	35,000	420	0.270	<0.001	0.0100	0.0170	0.0100	<0.0002	<0.01	<0.002	0.0830
	1:15 PM	Parker Rd	2,060	8.1	7.5	6.3	3.6	ND	39,000	104	0.130	<0.001	0.0110	0.0200	0.0090	<0.0002	<0.01	<0.002	0.1010
	1:05 PM	Homestead St	2,020	7.8	7.4	6.1	3.1	ND	34,000	532	0.200	<0.001	0.0140	0.0260	0.0140	<0.0002	<0.01	<0.002	0.1080
4/8/02	12:54 PM	Allwood St								186	0.210	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0470
	12:45 PM	Parker Rd								384	0.310	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0400
	12:35 PM	Homestead St								344	0.330	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0370
10/29/02	1:00 AM	Allwood St	50	7.4	7.3	4.2	3.2	ND	34,000	328	<0.10	<0.001	<0.005	<0.01	0.0060	<0.0002	<0.01	<0.002	0.0390
	12:45 AM	Parker Rd	3,680	7.8	7.5	4.3	2.8	ND	39,000	557	0.110	<0.001	<0.005	<0.01	0.0100	<0.0002	<0.01	<0.002	0.0460
	12:30 AM	Homestead St	3,810	7.9	7.7	4.9	3.6	ND	44,000	519	0.700	<0.001	<0.005	<0.01	0.0120	<0.0002	<0.01	<0.002	0.0720
7/9/03	9:15 PM	Homestead St	140	7.3	6.7	5.2	4.1	ND	44,000	147	0.17	<0.001	<0.005	<0.01	0.007	<0.0002	<0.01	<0.002	0.084
	9:40 PM	Parker Rd	135	7.3	6.4	6.7	4.5	ND	51,000	130	0.27	<0.001	<0.005	<0.01	0.006	<0.0002	<0.01	<0.002	0.066
	9:55 PM	Allwood St	10	7.3	6.8	3.7	3.0	ND	16,000	138	0.11	<0.001	<0.005	<0.01	0.005	<0.0002	<0.01	<0.002	0.039
11/17/03	9:00 PM	Homestead St	3,200	7.8	7.0	3.5	3.0	ND	41,000	448	<0.10	<0.001	<0.005	<0.01	0.010	<0.0002	<0.01	<0.002	0.035
	9:15 PM	Parker Rd	3,100	7.8	6.9	3.5	2.9	ND	49,000	505	<0.10	<0.001	<0.005	<0.01	0.007	<0.0002	<0.01	<0.002	0.034
	9:40 PM	Allwood St	150	7.4	6.7	3.9	3.4	ND	NO DATA	185	<0.10	<0.001	<0.005	<0.01	0.005	<0.0002	<0.01	<0.002	0.035
5/1/04	4:55 PM	Homestead St	1,500	7.0	6.6	6.3	4.9	ND	41,000	360	0.18	<0.001	<0.005	<0.01	0.010	<0.0002	<0.01	<0.002	0.052
	5:10 PM	Parker Rd	1,600	6.9	6.6	4.8	3.8	ND	55,000	298	0.20	<0.001	<0.005	<0.01	0.016	<0.0002	<0.01	<0.002	0.058
	5:25 PM	Allwood St	20	7.1	7.4	4.1	3.5	ND	45,000	114	<0.10	<0.001	<0.005	<0.01	0.010	<0.0002	<0.01	<0.002	0.050
6/23/04	11:25 PM	Homestead St	1,890	6.8	6.5	5.3	4.6	ND	45,000	81	0.35	<0.001	<0.005	<0.01	0.011	<0.0002	<0.01	<0.002	0.049
6/24/04	12:15 AM	Parker Rd	1,880	7.1	6.6	4.7	3.4	ND	49,000	500	<0.10	<0.001	<0.005	<0.01	0.011	<0.0002	<0.01	<0.002	0.101
	12:35 AM	Allwood St	20	7.1	5.6	4.4	3.5	ND	38,000	495	<0.10	<0.001	<0.005	<0.01	0.013	<0.0002	<0.01	<0.002	0.053
	1:15 PM	Homestead St	1,250	6.8	6.5	3.8	2.6	ND	31,000	237	0.15	<0.001	<0.005	<0.01	0.009	<0.0002	<0.01	<0.002	0.043
	1:30 PM	Parker Rd	1,180	7.4	6.4	3.9	2.7	ND	29,000	181	<0.10	<0.001	<0.005	<0.01	0.007	<0.0002	<0.01	<0.002	0.047
	1:45 PM	Allwood St	40	7.6	6.8	2.9	2.1	ND	32,000	196	<0.10	<0.001	<0.005	<0.01	0.010	<0.0002	<0.01	<0.002	0.064
6/25/04	11:05 AM	Homestead St	1,005	6.7	6.7	4.5	2.9	ND	38,000	505	0.21	<0.001	<0.005	<0.01	0.013	<0.0002	<0.01	<0.002	0.071
	11:16 AM	Parker Rd	950	7.4	6.4	3.7	2.8	ND	41,000	599	0.18	<0.001	<0.005	<0.01	0.017	<0.0002	<0.01	<0.002	0.069
	11:30 AM	Allwood St	25	7.7	6.6	3.3	2.2	ND	28,000	372	0.13	<0.001	<0.005	<0.01	0.014	<0.0002	<0.01	<0.002	0.084

Source: City of Hous Allwood St - Tributary Sampling Point Homestead St - Downstream Sampling Poi Parker Rd - Upstream Sampling Point ND = Non-detection

TABLE 7.11
COMPARISON BETWEEN UPSTREAM AND DOWNSTREAM SAMPLING OF NORTHSIDE WWF (USING DATA AT 69TH ST PLANT)

	Flow (cfs)	pH	Dis. Oxygen (mg/l)	CBOD (mg/l)	Cl_2 (mg/l)	Fecal Coliform (# per 100 ml)	TSS (mg/l)	NH_3-N (mg/l)
Northside WWF	91.6	7.2	6.6	46.1	0.44	722,759	84	5.30
Hirsch St (upstream of WWF)	7383.5	7.6	7.5	4.7	Non-detection	28,477	365	0.24
69th St Plant (downstream of WWF)	7351.1	7.6	7.4	5.0	Non-detection	31,663	445	0.42
Significant difference between upstream and downstream sampling? [3]		No	No	No		No	No	Yes

[1] Values shown are averages (or geometric means for FC) for sampling performed from 3/98 to 5/04.
[2] Only the WWF discharge events that have corresponding bayou monitoring data are considered in the average.
[3] Null hypothesis: upstream mean = downstream mean; alternative hypothesis: upstream mean > downstream mean for pH, DO, TSS, upstream mean < downstream mean for CBOD, FC, NH_3-N. Test at 95% confidence level.

TABLE 7.12
COMPARISON BETWEEN UPSTREAM AND DOWNSTREAM SAMPLING OF BELMONT WWF

	Flow (cfs)	pH	Dis. Oxygen (mg/l)	CBOD (mg/l)	Cl_2 (mg/l)	Fecal Coliform (# per 100 ml)	TSS (mg/l)	NH_3-N (mg/l)
Belmont WWF	15.5	7.3	6.6	37.0	1.83	3,980	77	2.56
Calhoun St (upstream of WWF)	7415.9	7.8	8.4	3.8	Non-detection	24,389	157	0.43
Lidstone St (downstream of WWF)	7446.1	7.8	8.2	3.8	Non-detection	22,712	187	0.43
Significant difference between upstream and downstream sampling? [3]		No	No	No		No	No	No

[1] Values shown are averages (or geometric means for FC) for sampling performed from 3/98 to 5/04.
[2] Only the WWF discharge events that have corresponding bayou monitoring data are considered in the average.
[3] Null hypothesis: upstream mean = downstream mean; alternative hypothesis: upstream mean > downstream mean for pH, DO, TSS, upstream mean < downstream mean for CBOD, FC, NH_3-N. Test at 95% confidence level.

TABLE 7.13
COMPARISON BETWEEN UPSTREAM AND DOWNSTREAM SAMPLING OF BRETSHIRE WWF

	Flow (cfs)	pH	Dis. Oxygen (mg/l)	CBOD (mg/l)	Cl_2 (mg/l)	Fecal Coliform (# per 100 ml)	TSS (mg/l)	NH_3-N (mg/l)
Bretshire WWF	4.6	7.3	6.3	22.0	0.42	216,364	75	1.81
Parker Road (upstream of WWF)	1978.8	7.5	7.4	3.1	Non-detection	40,723	361	0.17
Homestead St (downstream of WWF)	2006.5	7.4	7.4	3.3	Non-detection	36,620	349	0.22
Significant difference between upstream and downstream sampling? [3]		No	No	No		No	No	No

[1] Values shown are averages (or geometric means for FC) for sampling performed from 9/98 to 6/04.
[2] Only the WWF discharge events that have corresponding bayou monitoring data are considered in the average.
[3] Null hypothesis: upstream mean = downstream mean; alternative hypothesis: upstream mean > downstream mean for pH, DO, TSS, upstream mean < downstream mean for CBOD, FC, NH_3-N. Test at 95% confidence level.

TABLE 7.14
COMPARISON BETWEEN UPSTREAM AND DOWNSTREAM SAMPLING OF NORTHSIDE WWF (USING DATA AT LOCKWOOD ST)

	Flow (cfs)	pH	Dis. Oxygen (mg/l)	CBOD (mg/l)	Cl_2 (mg/l)	Fecal Coliform (# per 100 ml)	TSS (mg/l)	NH_3-N (mg/l)
Northside WWF	117.9	7.3	6.4	64.2	0.49	1,480,035	93	6.81
Hirsch St (upstream of WWF)	10321.0	7.7	7.4	5.3	Non-detection	28,591	332	0.27
Lockwood St (downstream of WWF)	10321.0	7.8	7.6	5.7	Non-detection	32,275	324	0.31
Significant difference between upstream and downstream sampling? [3]		No	No	No		No	No	No

[1] Values shown are averages (or geometric means for FC) for sampling performed from 9/98 to 9/02.
[2] Only the WWF discharge events that have corresponding bayou monitoring data are considered in the average.
[3] Null hypothesis: upstream mean = downstream mean; alternative hypothesis: upstream mean > downstream mean for pH, DO, TSS, upstream mean < downstream mean for CBOD, FC, NH_3-N. Test at 95% confidence level.

CHAPTER 8

ASSESSMENT OF *E. COLI* DOWNSTREAM OF WASTEWATER TREATMENT PLANT OUTFALLS

This chapter summarizes the progress made between July 14 and August 31, 2004 with respect to WWTP outfall sampling. A description of the methods and technical approach undertaken to complete this task is presented below. All the sampling and analysis procedures employed for this task followed those outlined in the approved QAPP for this project.

The goal of this task was to understand the relationship, if any, between treated wastewater effluent and EC levels downstream of a wastewater plant outfall. Ten locatable wastewater outfalls were sampled during dry weather (defined as 3 or more days without rain). Four samples were collected at each wastewater plant: (1) approximately 300 ft upstream of the outfall, (2) at the outfall in the stream, (3) from the outfall , and (4) downstream from the outfall (at approximately 300 ft), past the mixing zone, as determined by the equation

$$L_m = 2.6U\frac{B^2}{H}$$

where L_m is the distance from the outfall to where the discharge has been well mixed laterally, U is the average stream velocity, B is the average stream width, and H is the average stream depth (Thomann and Mueller, 1987). Samples were analyzed for EC and TSS levels. The velocity of the stream was roughly estimated using an object in the stream and measuring its distance for a fixed period of time. Flow from the outfall was estimated by measuring the volume discharged in a 1-minute period in a calibrated cylinder. Sampling activities also included a field measurement of residual chlorine using a HACH colorimeter and measuring conventional field parameters (DO, turbidity, conductivity, pH, and temperature) using a YSI multiparameter sonde (600XLM or 6920).

Figure 8.1 shows the locations of the sampled outfalls and associated sampling locations. Table 8.1 provides a summary of field parameter measurements and Table 8.2 presents the results of the laboratory analyses.

Overall, EC concentrations in ambient water varied between <1 and 15,117 MPN/dL with a geometric mean of 156 MPN/dL. EC levels in outfall samples varied between <1 and 5,905 MPN/dL with a geometric mean of 17 MPN/dL. It is noted that in-stream EC levels exceeded the water quality standard (126 MPN/dL) in 22 of the 30 locations (73%) sampled for this task. The highest in-stream EC levels were found at locations downstream of outfalls WQ10495-099 (15,117 MPN/dL) and WQ12465-001 (6,938 MPN/dL). The highest EC concentration in effluent was measured at outfall WQ10495-099 (5,905 MPN/dL).

No obvious trend was inferred from the longitudinal profiles as shown in Figure 8.2. Overall, the outfalls selected for sampling did not seem to cause any negative impact on the in-stream EC levels at the discharge point or downstream of it as indicated by downstream concentrations that are generally as high or lower than their upstream counterparts. The only exceptions are samples collected downstream of plants WQ12465-001 and WQ10495-099, both in Whiteoak Bayou. The longitudinal profile for WQ12465-001 shows a high EC concentration in the upstream sample with very low (non-detect) concentrations in the in-stream and effluent samples and a dramatic increase in EC concentration for the downstream sample. Because the outfall concentration is so low, it is unlikely that the increase in downstream concentration is caused by effluent discharge. On the other hand, the longitudinal profile for WQ10495-099 shows a moderate EC concentration in the upstream sample (182 MPN/dL), a very low in-stream concentration, and a dramatic increase in the downstream sample (15,117 MPN/dL). The EC concentration in the outfall sample was high (5,905 MPN/dL) and, thus, the increase in downstream EC concentration may be somewhat related to the discharged effluent.

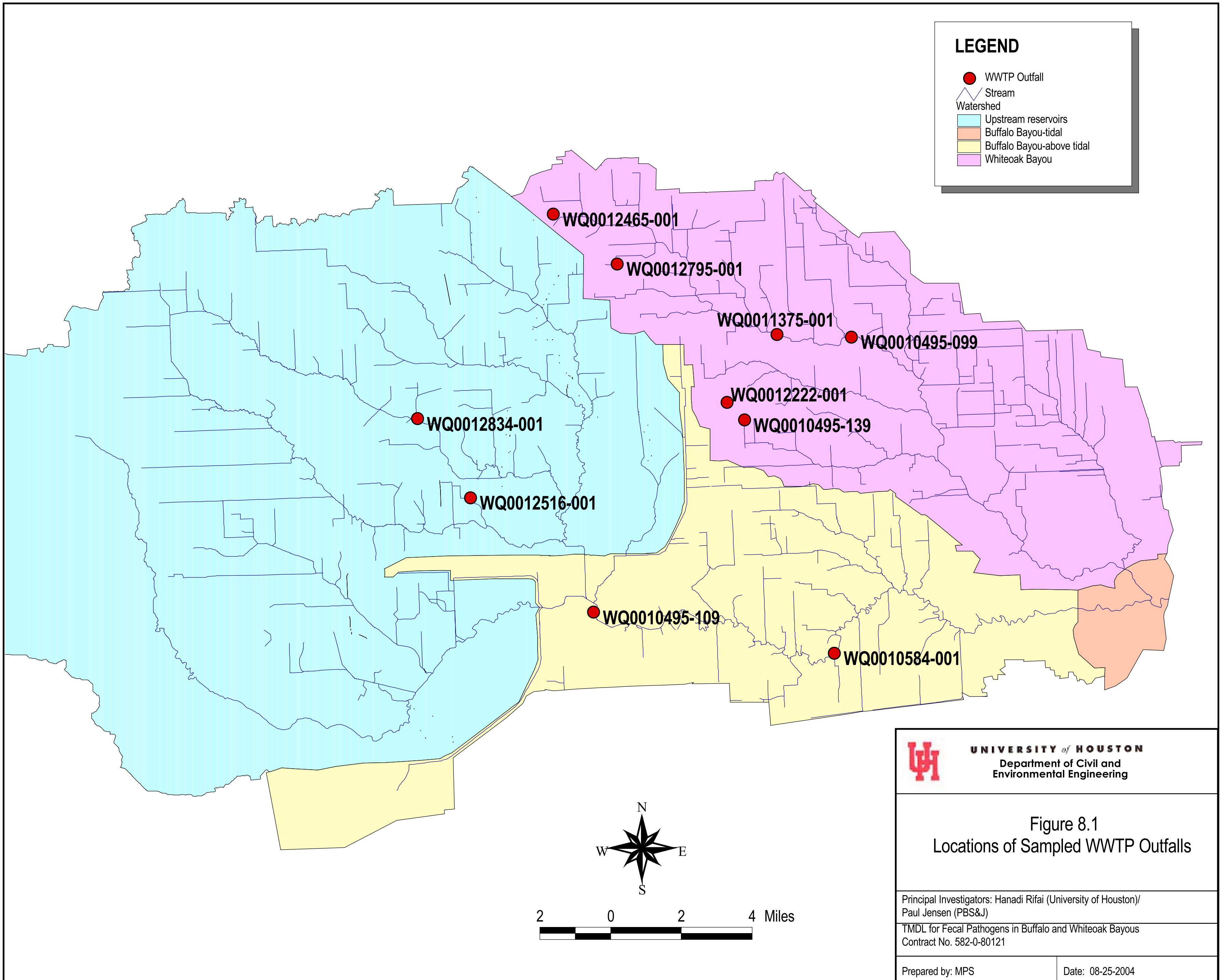


Figure 8.1
Locations of Sampled WWTP Outfalls

Table 8.1 Field Measurements Collected during WWTP Outfall Sampling

Sample ID	Plant Name	Date	Time	Temp (^oC)	Conductivity ($\mu S/cm$)	DO (mg/L)	pH	Residual Chlorine (mg/L)	Phosphorous (mg/L)	Stream Velocity (ft/s)	Effluent Flow (L/s)	Flow (MGD)
12465-001-D	Tifco	06/14/04	11:00	28.8	482	4.69	7.0	0.03	2	0.0		
12465-001-I	Tifco	06/14/04	11:05	28.85	569	7.93	7.0	0.88		0.0		
12465-001-E	Tifco	06/14/04	11:12	28.17	558	8.38	7.0	1.39	7.94	na	0.453	0.010
12465-001-U	Tifco	06/14/04	11:32	32.1	293	5.63	7.0	0.07	1.78	0.0		
10495-139-D	City of Houston-Westway MUD	06/15/04	9:35	24.95	777	7.42	6.9	1.08	1.01	nm		
10495-139-I	City of Houston-Westway MUD	06/15/04	9:40	25.17	843	8.65	6.9	4.8	1.66	nm		
10495-139-E	City of Houston-Westway MUD	06/15/04	9:55	24.8	692	7.11		0.64	0.95	nm	nm	nm
10495-139-U	City of Houston-Westway MUD	06/15/04	10:19	24.02	348	3.14	6.8	0	1.19	nm		
10495-099-D	City of Houston-Whiteoak MUD	06/21/04	9:50	30.3	817	5.52	7.4	0.05	5.05	0.5		
10495-099-I	City of Houston-Whiteoak MUD	06/21/04	10:10	28.08	997	8.02	7.4	0.03	4.08	0.5		
10495-099-E	City of Houston-Whiteoak MUD	06/21/04	10:25	28.05	946	8.24	7.4	0	7.08	na	nm	nm
10495-099-U	City of Houston-Whiteoak MUD	06/21/04	10:35	30.34	818	6.16	7.5	0.06	3.08	0.5		
11375-001-D	Creekside Utilities	06/22/04	9:00	29.05	693	6.47	7.1	0.08	4.32	0.2		
11375-001-I	Creekside Utilities	06/22/04	9:30	28.96	693	6.58	7.1	0.01	3.73	0.2		
11375-001-E	Creekside Utilities	06/22/04	9:45	27.68	942	8.35	7.1	3.05	6.95	na	nm	nm
11375-001-U	Creekside Utilities	06/22/04	10:00	28.89	695	6.703	7.1	0.06	21.55	0.2		
12222-001-D	WXNW	06/29/04	13:35	27.19	528	5.16	6.5	0.05	5	0.2		
12222-001-E	WXNW	06/29/04	13:55	27	781	7.92	7.0	3.7	17.15		0.833	0.019
12222-001-I	WXNW	06/29/04	15:00	26.75	481	5.23	7.0	0.05	3.75	0.2		
12222-001-U	WXNW	06/29/04	15:10	26.91	475	5.6	7.0	0.03	2.94	0.2		
12795-001-D	Northwest Harris County MUD 29	06/30/04	8:40	27.59	1003	6.29	6.5	0.12	7.45	0.1		
12795-001-I	Northwest Harris County MUD 29	06/30/04	9:07	27.12	947	6.51	6.7	1.1	5.44	0.1		
12795-001-U	Northwest Harris County MUD 29	06/30/04	9:44	25.16	631	5.83	7.1	0.03	0.48	0.1		
12795-001-E	Northwest Harris County MUD 29	06/30/04	Not collected because pipe was submerged									
12516-001-D DUP	West Houston Airport	07/12/04	10:20	na	na	na	na	na	na	na	na	na
12516-001-D	West Houston Airport	07/12/04	10:20	27.73	894	8.73	7.5	0.12	10.44	2.7		
12516-001-I	West Houston Airport	07/12/04	10:57	27.87	903	11.34	7.5	0.17	8.48	2.7		
12516-001-E	West Houston Airport	07/12/04	10:57	28.85	907	11.61	7.5	0.16	8.04	na	0.263	0.006
12516-001-U	West Houston Airport	07/12/04	11:05	26.38	347	10.7	7.5	0	0.88	2.7		
12834-001-D	Greenhouse Rd	07/13/04	10:10	28.72	305	7.43	7.4	0	1.96	<0.008		
12834-001-I	Greenhouse Rd	07/13/04	10:30	28.28	307	7.29	7.3	0	1.9	<0.008		
12834-001-E	Greenhouse Rd	07/13/04	10:45	na	na	na	na	0.07	0.0	na	0.001	2.66E-05
12834-001-U	Greenhouse Rd	07/13/04	11:17	28.65	312	7.2	7.2	0	1.92	<0.008		

Table 8.1 Field Measurements Collected during WWTP Outfall Sampling

Sample ID	Plant Name	Date	Time	Temp (°C)	Conductivity (µS/cm)	DO (mg/L)	pH	Residual Chlorine (mg/L)	Phosphorous (mg/L)	Stream Velocity (ft/s)	Effluent Flow (L/s)	Flow (MGD)
10495-109-E	City of Houston-Turkey Creek	08/05/04	8:35	na	na	na	na	0.2	5.26	na	nm	nm
10495-109-E DUP	City of Houston-Turkey Creek	08/05/04	8:35	na	na	na	na	0.15	5.18	na		
10495-109-U	City of Houston-Turkey Creek	08/05/04	8:42	na	na	na	na	0.03	3.13	1.5	nm	
10495-109-I	City of Houston-Turkey Creek	08/05/04	8:45	na	na	na	na	0.12	3.01	1.5		
10495-109-D	City of Houston-Turkey Creek	08/05/04	9:00	na	na	na	na	0.04	3.75	1.5		
10584-001-E	Memorial Villages	08/13/04	8:41	28.38	803	0.49	7.9	0	6.02	nm	nm	nm
10584-001-E DUP	Memorial Villages	08/13/04	8:41	na	na	na	na	na	na	nm	nm	nm
10584-001-I	Memorial Villages	08/13/04	8:46	26.37	762	0.7	7.7	0	4.48	1.9		
10584-001-U	Memorial Villages	08/13/04	8:55	26.4	761	0.62	7.7	0.02	5.08	1.9		
10584-001-D	Memorial Villages	08/13/04	9:26	26.37	762	0.7	7.7	0.17	2.47	1.9		

Notes/Abbreviations:

E denotes a sample collected directly from the outfall
U denotes a sample collected upstream of the outfall
I denotes a sample collected in-stream at the point of discharge of the outfall
D denotes a sample collected downstream of the outfall
WWTP = wastewater treatment plant
na = not available
MUD = municipal utility district

mg = milligram
µS = micro Siemens
MGD = million gallons per day
nm = not measurable (flow/velocity too high to be quantified)
L = liter
cm = centimeter
DUP = duplicate

Table 8.2 Laboratory Results for WWTP Outfall Sampling

Sample ID	Plant Name	Date	Total Coliform (MPN/dL)	EC (MPN/dL)	EC Confidence Interval (MPN/dL)	TSS (mg/L)	TDS (mg/L)
12465-001-D	Tifco	06/14/04	>241920	6938	6938±2011	5.0	227.0
12465-001-E	Tifco	06/14/04	10	<1		5.0	322.0
12465-001-I	Tifco	06/14/04	2291	<1		20.0	298.0
12465-001-U	Tifco	06/14/04	50730	413	413±122	220.0	234.0
10495-139-D	City of Houston-Westway MUD	06/15/04	2	<1		6.0	397.0
10495-139-I	City of Houston-Westway MUD	06/15/04	712	<1		6.0	484.0
10495-139-I DUP	City of Houston-Westway MUD	06/15/04	378	9		7.0	487.0
10495-139-U	City of Houston-Westway MUD	06/15/04	>241920	6833	6833±1415	18.0	223.0
10495-099-D	City of Houston-Whiteoak MUD	06/21/04	129582	15117	15117±3075	31.2	455.0
10495-099-E	City of Houston-Whiteoak MUD	06/21/04	48327	5905	5905±1463	< 4	568.0
10495-099-I	City of Houston-Whiteoak MUD	06/21/04	521	<1		39.2	456.0
10495-099-U	City of Houston-Whiteoak MUD	06/21/04	1817	183	183±53	39.2	448.0
11375-001-D	Creekside Utilities	06/22/04	56515	1152	1152±35	46.4	398.0
11375-001-E	Creekside Utilities	06/22/04	<1	<1		< 4	523.0
11375-001-I	Creekside Utilities	06/22/04	41060	1221	1221±107	51.6	384.0
11375-001-U	Creekside Utilities	06/22/04	89768	858	858±30	36.4	383.0
12222-001-D	WXNW	06/29/04	>241920	178	178±32	24.4	367.0
12222-001-E	WXNW	06/29/04	<1	<1		9.0	725.0
12222-001-I	WXNW	06/29/04	>241920	251	251±37	19.6	376.0
12222-001-U	WXNW	06/29/04	>241920	342	342±145	24.4	336.0
12795-001-D	Northwest Harris County MUD 29	06/30/04	47	10		12.0	686.0
12795-001-D-DUP	Northwest Harris County MUD 29	06/30/04	345	5		14.0	696.0
12795-001-I	Northwest Harris County MUD 29	06/30/04	14	<1		10.4	783.0
12795-001-I-DUP	Northwest Harris County MUD 29	06/30/04	8	10		14.0	809.0
12795-001-U	Northwest Harris County MUD 30	06/30/04	54750	955	955±242	49.0	467.0

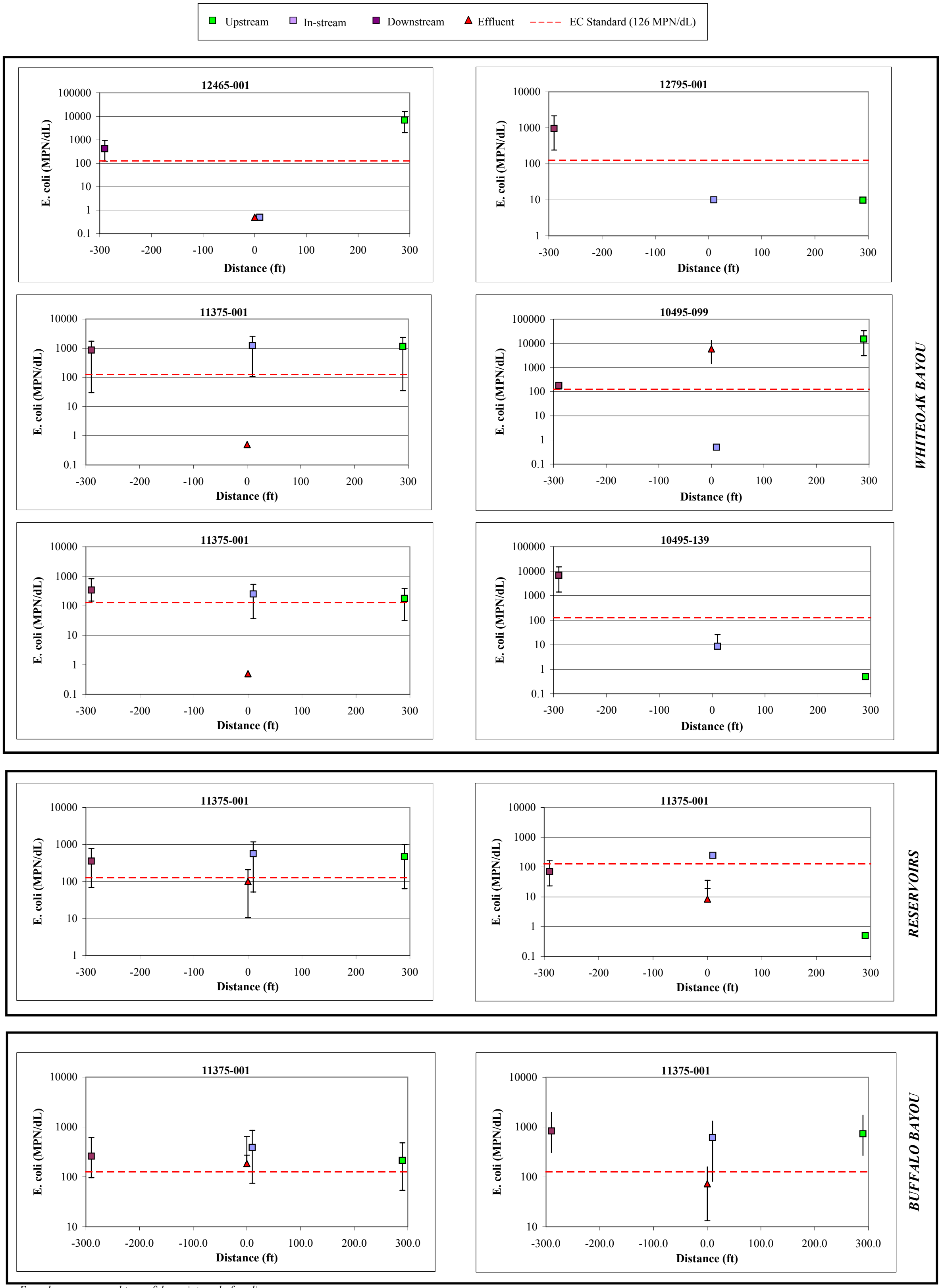
Table 8.2 Laboratory Results for WWTP Outfall Sampling

Sample ID	Plant Name	Date	Total Coliform (MPN/dL)	EC (MPN/dL)	EC Confidence Interval (MPN/dL)	TSS (mg/L)	TDS (mg/L)
12516-001-D	West Houston Airport	07/12/04	7	<1		14.4	520.0
12516-001-E	West Houston Airport	07/12/04	459	8	8±19	8.8	520.0
12516-001-I	West Houston Airport	07/12/04	8814	248		49.6	472.0
12516-001-U	West Houston Airport	07/12/04	30653	70	70±23	60.8	245.0
12516-001-D DUP	West Houston Airport	07/12/04	1	<1		7.2	519.0
12834-001-D	Greenhouse Rd	07/13/04	96261	469	469±64	34.0	413.0
12834-001-E	Greenhouse Rd	07/13/04	29390	100	100±11	48.8	286.0
12834-001-I	Greenhouse Rd	07/13/04	89043	561	561±52	27.2	430.0
12834-001-U	Greenhouse Rd	07/13/04	61310	356	356±69	22.8	431.0
10495-109-D	City of Houston-Turkey Creek	08/05/04	45247	214	214±54	56.0	494.0
10495-109-I	City of Houston-Turkey Creek	08/05/04	53843	390	390±74	86.0	448.0
10495-109-E	City of Houston-Turkey Creek	08/05/04	4170	186	186±273	4.0	547.0
10495-109-U	City of Houston-Turkey Creek	08/05/04	51720	261	261±96	65.0	458.0
10495-109-E-DUP	City of Houston-Turkey Creek	08/05/04	4922	56	56±26	4.0	565.0
10584-001-D	Memorial Villages	08/13/04	39507	734	734±269	26.0	504.0
10584-001-I	Memorial Villages	08/13/04	29647	619	619±82	16.0	556.0
10584-001-E	Memorial Villages	08/13/04	1373	73	73±13	<1	500.0
10584-001-U	Memorial Villages	08/13/04	32130	835	835±310	22.0	524.0

Notes/Abbreviations:

E denotes a sample collected directly from the outfall
U denotes a sample collected upstream of the outfall
I denotes a sample collected in-stream at the point of discharge of the outfall
D denotes a sample collected downstream of the outfall
WWTP = wastewater treatment plant
EC = *Escherichia coli (E. coli)*

MPN = most probable number
MUD = municipal utility district
mg = milligram
L = liter
dL = deciliter
DUP = duplicate



Error bars correspond to confidence interval of media

Figure 8.2 Results of WWTP Outfall Sampling

CHAPTER 9

BACTERIA SOURCE TRACKING

Bacteria source tracking - the determination of the animal source(s) of fecal contamination using characteristics of bacteria - is a rapidly growing field. There are a number of techniques used for this tracking, including both phenotypic and genotypic methods. The underlying principle for all these methods is that bacteria growing in intestinal tracts of different animals have different characteristics which can be assessed in different ways. As an example, antibiotic resistance of bacteria is affected by a number of factors including host animal exposure (or treatment with) antibiotics. Bacteria in wildlife would be expected to show less resistance to antibiotics than human, pets or domestic animals. Currently, there is considerable debate as to which methods provide the best information at the lowest cost. A recent comparative study by Griffith et al. (2003) concluded that none of the 12 source tracking methods they tested, provided a perfect characterization of the fecal source material in the test samples. Each method had a different set of positive attributes e.g. cost, accuracy etc. Phenotypic methods such as antibiotic resistance testing have the advantage of lower cost and faster processing, but the molecular techniques generally provide a better discrimination between bacterial strains.

In this project antibiotic resistance analysis (ARA) was enhanced by analyzing a subset of the isolates by Pulse Field Gel Electrophoresis (PFGE), a molecular technique which generates a DNA “fingerprint” specific for different strains of the bacteria. Several bacteria have been used for source tracking purposes, the main requirement is that they are specific to the intestinal tracts of animals. In this study *Escherichia coli* was used as the bacterium. It is one of the bacteria recommended by the Environmental Protection Agency as an indicator of fecal contamination in fresh waters.

The first step in the two methods employed in this study was to isolate *E. coli* from fecal samples of animals thought to contribute to fecal contamination of the WhiteOak and Buffalo Bayous. These bacteria were isolated, using specific growth media, and then verified using the Biolog MicroLog™ Microbial Identification System. After verifying that the bacteria are *E. coli*, each isolate was tested for its characteristics.

Antibiotic resistance analysis was performed using the Kirby Bauer Disk Diffusion Test, a clinically approved, standard method for testing bacteria for their resistance to a range of antibiotics. Commercial disks, each containing an antibiotic, are placed on a plate, pre-inoculated with the *E. coli* isolate. After incubation the plates are read using a BIOMIC® Microbiology Analyzer System plate reader which includes a high resolution digital color camera. The plates are assessed for zones of inhibition (no growth) around the disks (indicating the bacteria are susceptible to the antibiotic) or reduced zones (indicating the bacteria can grow in the presence of the antibiotic and are resistant/intermediate). The information is compared with NCCLS tables of standard zones for *E. coli*, included in the BIOMIC® computer software. A printout is generated which includes zones of inhibition and resistance classification.

The information from each isolate is entered into a database, converted to SPSS® and analyzed to determine whether the isolates from different animals have different antibiotic resistance profiles. This ‘library’ can then be used to identify sources of *E. coli* from water/sediment samples by comparing these profiles. Pulse Field Gel Electrophoresis entails growing the isolates and after several steps, preparing a DNA plug extracted from the bacteria. The DNA is then cut using a restriction enzyme and run on a gel which separates the DNA into bands based on size. The bands formed by DNA from *E. coli* of different animal sources can be compared and again, used as a library for identification of sources of unknown *E. coli* from water/sediment studies. In this project, the ARA and PFGE libraries were developed and statistical analysis initiated to test the libraries. Due to the restricted time for analysis in year 1, the libraries will continue to be tested as unknown sample isolates are analyzed.

9.1 SOURCE SAMPLING

Fecal specimens from known animal sources were collected from the Houston area by Texas A&M University-Corpus Christi and University of Houston personnel on two sampling trips (June 17-18, 2004 and July 1-2, 2004). The animal species from which fecal samples were collected were chosen based on sanitary surveys of the area previously conducted by University of Houston personnel (Table 9.1). General areas from which samples were collected are shown in Table 9.2. Specific locations and businesses are not identified at the request of owners. A more detailed confidential list is stored with the Chain of Custody Forms at Texas A&M University-Corpus Christi.

All collection protocols followed those detailed in the Quality Assurance Project Plan (QAPP). Samples from animal sources were collected using BBL™ EZ Culture Swabs and/or sample cups. Sterile culture swabs were opened and immediately applied to a fecal sample and returned to the sterile plastic container enclosing the swab. For samples collected in sample cups, sterile tongue depressors were used to remove the top portion of the fecal sample and a second tongue depressor was utilized to obtain the sample. The sample was then placed immediately into an unopened sample cup and sealed. All samples were put directly onto ice until further

Table 9.1 Animal sources used for the known source library

Animal Source and Abbreviation used	**Scientific Name**
Human (H)	*Homo sapiens*
Cow ©	*Bos taurus*
Dog (D)	*Canis lupis familiaris*
Bat (G) - Mexican free-tailed	*Tadarida brasiliensis*
Horse (E)	*Equus caballus*
Bird (B) (pigeon and others)	Mixed species

Table 9.2. Dates and locations of fecal sample collections

Date	Sample Identification	Geographical Location
06/17/04	Cow C1-C44	Addicks Reservoir/Buffalo Bayou Waterway (Grass Fed Cattle Lot)
06/17/04	Cow C45-C85	Addicks Reservoir/Buffalo Bayou Waterway (Feed Cattle Lot)
06/17/04	Bird B1-B8	Addicks Area of Houston (Concrete Sidewalk)
06/17/04	Bird B9-B29	N. Central Houston
06/17/04	Horse E1-E25	Addicks Reservoir/ Buffalo Bayou (Manure Pile)
06/17/04	Bat G1-G85	Beechnut/Isobel Bat House
06/17/04	Dog D1	Addicks Area
06/18/04	Human H1-H85	N.E. Houston/Little York (Broken Filtered Sewage Line)
06/18/04	Bat G86-G93	Waugh/E. Downtown (Under Overpass)
06/18/04	Dog D2-D7	E. Buffalo Bayou (Grass Lot)
06/18/04	Dog D8-D16	IH-610 W Loop ("Relief" Area Outside Vet Office)
06/18/04	Dog D17-D20	Meyerland (Vet Samples…No Antibiotics)
07/01/04	Horse E26-E51	Addicks Reservoir (Grass Fed Horse Lot)
07/01/04	Horse E52-95	Pearland Area (Large Stables Area and Manure Pile)
07/01/04	Cow C86-C125	Addicks Reservoir (Large Grass Fed Lot)
07/01/04	Human H86-170	N.E. Houston/Little York (Unprocessed Fresh Portable Toilet Release Vat)
07/01/04	Bat G94-G96	Central Downtown (Underpass)
07/01/04	Dog D21-D34	NW Houston (Kennels)
07/01/04	Dog D68-D85	Central Downtown (Grass Area Frequented by Dogs)
07/02/04	Bat G97-G115	Central Downtown (Underpass)
07/02/04	Bird B31-B90	Central Downtown (Large Concreted Location; Frequented by Pigeons)

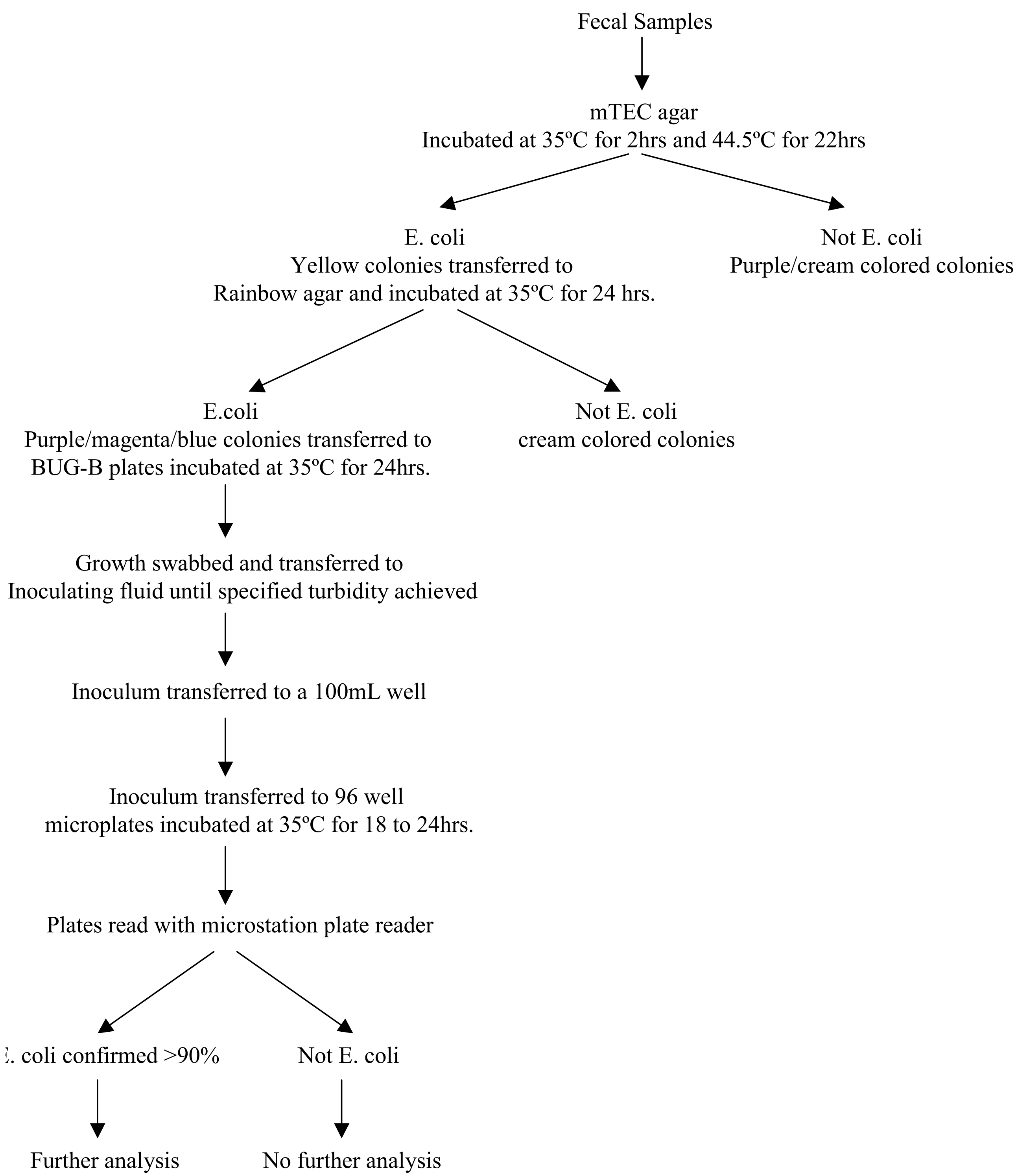
analyses could be conducted. Note: Bird samples were not collected using the "tarp" method from previous studies due to sufficient fresh samples found in concrete areas.

9.2 *E. coli* ISOLATIONS

Samples were transported to the Environmental Microbiology Research Lab at Texas A&M University-Corpus Christi on ice, in coolers on June 18 and July 2, 2004. Analysis followed methods described in the QAPP and a flow chart summarizing the following discussion can be found in Figure 9.1.

Fecal samples were swabbed onto mTEC agar and incubated at 35ºC for 2hr and 44.5ºC for 22hr. Yellow colonies were transferred from mTEC onto Rainbow® Agar and incubated at 35ºC for 24hr. One to five isolates were obtained from each sample. Colonies showing a colored hue (i.e. blue, purple, magenta) on Rainbow Agar were transferred for verification as *E. coli* using the BioLog MicroLog™ or MicroStation™ Microbial Identification System, a microplate method which identifies bacteria using a panel of carbon sources prepared in the wells of the microplate. Use of this procedure provided verification that the isolates were *E. coli* and not some closely related species which can grow on the initial medium used for isolation from the fecal sample. Bacteria are first grown on specific plates, obtained from Biolog, and then prepared in a liquid medium at a certain turbidity for inocluation of microplates. The plates, with 96 wells are inoculated using an 8-lane pipettor and are incubated to allow the bacteria to grow. The plates are read with a plate reader. If the carbon source has been used, the well turns a purple color. Based on the pattern of colors in the 96-wells, software included with the plate reader generates an identification and probability level for that identification. All steps in this process followed manufacturer’s instructions.. Each isolate was swabbed for maximum growth onto

Figure 9.1
***E. coli* Isolation Procedure**



Biolog™ Universal Growth plates (BUG-B) and incubated at 35ºC for 24h. Cultures were transferred to inoculating fluid and a turbidity of 61% ± 2 % was achieved before inoculating GN2 Microplates™ as required per manufacturer's instructions, to optimize carbon source utilization in the wells. The plates were incubated for 24h at 35ºC and analyzed. Initial isolates were identified using the Biolog™ MicroLog System (manual readings). After funding was provided to purchase a MicroStation, the majority of the isolates were identified with a semi-automated MicroStation Microbial Identification System (MIS) with MicroLog Software using the MicroStation Reader for confirmation as *E. coli* and for well color intensity data. Samples were stored temporarily on Tryptic Soy Agar (TSA) slants immediately from BUG-B in order to maintain pure cultures between various analyses. Verified isolates were finally stored at -70ºC.

Isolates which were not confirmed by the MicroStation MIS were either closely related species or did not confirm at >90% probability. Sufficient isolates were confirmed to provide a database that exceeded the originally proposed number of isolates from each animal (Table 9.3).The most common species identified by the Biolog™ Microbial Identification System (MIS) other than *E. coli* included *Enterobacter intermedius, Salmonella* spp*., Leclercia adecarboxylata, Buttiauxella izardii, Buttiauxella agrestis, Klebsiella oxytoca, Rahnella aquatilis, Enterobacter aerogenes, Serratia odorifera*, and *Raoutella terrigena*. A sample print out from the MIS is included in Appendix F. The MicroStation MIS set is saved on a CD-ROM, labeled "Hou Biolog fecal" included with this report. Hard copies are stored at Texas A&M University-Corpus Christi.

Only isolates that were confirmed as *E. coli* (>90%) were included in the subsets used to develop the ARA (Antibiotic Resistance Analysis) and PFGE (Pulse Field Gel Electrophoresis) libraries. (Table 9.4)

Table 9.3 Number of known source isolates obtained and confirmed as *E. coli* (>90%)

Animal Source	**# Isolates**	**# Isolates Confirmed by MIS**	**# Isolates Stored**
Bird	365	174	174
Cow	426	220	220
Dog	306	182	182
Horse	348	200	200
Bat	389	204	204
Human	449	246	246
TOTAL	2283	1207	1207

Table 9.4 Number of known source isolates analyzed by Antibiotic Resistance Analysis (ARA) and Pulse Field Gel Electrophoresis (PFGE).

Animal Source	**ARA isolates**	**PFGE isolates**
Bird	171	63
Cow	219	58
Dog	182	59
Horse	200	53
Bat	204	59
Human	202	52
TOTAL	1178	344

Note: different numbers of isolates for ARA and PFGE, as specified in the Scope of Services which stated that 1000 isolates would be analyzed by ARA and 300 by PFGE.

9.3 SOURCE ANTIBIOTIC RESISTANCE ANALYSIS

Antibiotic resistance analysis, using a panel of 20 antibiotics (Table 9.5), was performed for each isolate following NCCLS (2000) Performance Standards for Antimicrobial Disc Susceptibility Tests, Approved Standard-Seventh Edition; NCCLS document M2-A7, NCCLS (2002) Performance Standards for Antimicrobial Disk and Dilution Susceptibility Tests for Bacteria Isolated from Animals, Approved Standard-Second Edition; NCCLS document M31-A2 NCCLS (2002) Performance Standards for Antimicrobial Susceptibility Testing, Twelfth Informational Supplement, and NCCLS document M100-S1, Methodology and Quality Controls. Duplicates were included for 20% of the isolates.

As described in the introduction, antibiotic resistance analysis assesses the ability of each isolate to grow in the presence of a panel of antibiotics. The isolate is swabbed on a Mueller-Hinton Agar plate and commercial disks, each containing an antibiotic, are placed on the plate. Each plate was inoculated with 10 disks, two plates being prepared for each isolate. If the isolate is susceptible (S) to the antibiotic in the disk, growth will be inhibited around the disk, forming a 'zone of inhibition". In contrast, if the bacteria have intermediate susceptibility or are resistant (I or R) the zone size is reduced. After incubation, the plates were read using the BIOMIC®Vision Antibiotic Susceptibility system, which uses cutting edge technology with NCCLS recommended methods and materials. NCCLS provides standard clinical tables of zone diameters for a range of bacteria, including *E. coli*. The BIOMIC® system was used for an instantaneous reading and interpretation following NCCLS M100 (2002). This system records zone diameters automatically from the standard disk diffusion method. Readings are instantaneous using a high resolution color digital camera. The printout includes the zone diameter and R:I:S categorization, as well as other parameters not used in this study, but important for clinical laboratories such as minimum inhibitory concentration, used to determine antibiotic dosages. BIOMIC® system software determines whether each isolate is resistant, intermediate or susceptible (R-I-S) based on published NCCLS guidelines, and updated yearly using current NCCLS data.

ATCC strains (standard strains from the American Type Culture Collection) are used to test the media and antibiotics for each new batch of media/antibiotics. The quality control strains were *Pseudomonas aeruginosa* ATCC 27853, *Staphylococcus aureus* ATCC 25923, and *E. coli* ATCC 25923. Controls were run weekly and for each new lot number of media or antibiotics. The BIOMIC EXPERT system software contains rules designed by experts to check for unusual or unlikely test results. Performance in acceptable range is indicated by "OK " on-screen and printouts after reading QC test plates. Messages are shown on the screen and on printouts where appropriate. This is designed to improve quality and reliability of results. Each time a rule is "triggered", it is recorded on the message tab for that report. This method has proven to improve reading consistency and speed thereby minimizing technologist variation.

The database is stored in the BIOMIC system computer with back-ups saved in the hard drive and on CD-ROM. A sample print-out showing the results for one isolate is included in Appendix F. The databases are stored on the CD-ROM enclosed with this report under two folders "Hou ARA RIS" and "Hou ARA Zone" - Resistant:Intermediate:Susceptible and zone diameters. The complete set of print-outs is stored at Texas A&M University-Corpus Christi.

Table 9.5. Antibiotics used to establish antibiotic resistance profiles of known source *E. coli* isolates.

Antibiotic	Abbreviation	Concentration (ug)
Amoxicillin/Clavulanate Acid	AmC	30
Ampicillin	AM	10
Chloramphenicol	C	30
Ciprofloxacin	CIP	5
Enrofloxacin	ENO	5
Gentamicin	GM	10
Kanamycin	K	30
Nalidixic acid	NA	30
Neomycin	N	30
Tetracycline	Te	30
Cefazolin	CZ	30
Ceftazidime	CAZ	30
Cefotaxime	CTX	30
Ceftriaxone	CRO	30
Doxycycline	D	30
Imipenem	IPM	10
Spectinomycin	SPT	100
Streptomycin	S	10
Sulfasoxazole	G	0.25
Sulfamethoxazole-Trimethoprim	SXT	23.75 /1.25

Data analysis was performed on all the isolates using SPSS® Version 11.0 for Windows. The antibiotic resistance profiles (zone diameter) for all isolates were compiled to form a database in SPSS® for Discriminant Analysis (stored on the enclosed CD-ROM in EXCEL as "Hou ARA"). Earlier studies have shown that RIS data (Resistant:Intermediate:Susceptible) does not provide as good discrimination between sources as zone diameter. Thus, for this study, analyses were conducted using the zone diameters only. The data may be re-analyzed using R:I:S categories for each isolate and antibiotic during year 2 to confirm that the zone diameter data is superior for library purposes.

Discriminant analysis is a multi-variate technique that can be used to classify items into categories based on a set of test variables (Huberty, 1994). The rates of correct classification (RCC) for each source can be used to evaluate the predictive capabilities of the database.

The zone diameter database of 1178 isolates, with 20 antibiotics was analyzed in a variety of ways, including various groupings of the isolates from different sources. Initial analysis was conducted on the data from all the antibiotics. Two-way, four-way, six-way and seven-way analyses were completed to determine average rates of correct classification (ARCC). This is the average of the rates of correct classification (RCC) for each group. Additional analyses used the step-wise method with Wilks' lambda to remove antibiotics which did not contribute or contributed little to the classification of isolates for possible improvement of classifications.

As classifications based upon the cases used to create the model tend to be too "optimistic" in the sense that their classification is inflated, cross-validation was performed to correct this by classifying each case while leaving it out from the model calculations (leave-one-out method).

Discriminant analysis tables are included in Appendix F and on the enclosed CD-ROM in the folder "discriminant analysis in Word". SPSS® data is included as a separate folder ("SPSS Data") on the CD-ROM.

The following sections summarize the statistical information generated by dividing the database into different groupings to determine how well isolates could be classified either from individual animals or groups of animals. In each section a table is included to show the ARCC - the average rate the classification allows the isolates to be correctly classified, the rate of correct classification for each group (RCC) when divided into these groups, and the cross-validation ARCC - to show how close it is to the original ARCC, which would indicate the library is representative.

9.3.1 TWO-WAY CLASSIFICATION (HUMAN VS. NON-HUMAN)

For TMDL purposes one of the key distinctions is between human and non-human sources of contamination. Isolates were, therefore, first grouped as human or non-human and analyzed. The results of the human vs. non-human analyses are summarized in Table 9.6.

A shown in the first two columns, using all the isolates and antibiotics, the average rate of correct classification (ARCC) was 77.4%, with an RCC of 83.3% for non-human and 49% for human. Stepwise analysis (Wilks' lambda) did not improve the classification. Cross validation reduced the ARCC only slightly, to 75.6% with 82.3% non-human and 43.6% human correctly classified.

On closer scrutiny of the data it was seen that the 'human' isolates collected from the two types of source (Table 9.2) - individual portable toilets and a broken pipeline from an open sewage vat in which the solids had been removed, differed in their characteristics. The

Table 9.6. Summary Table of Percent Average Rates of Correct Classification (ARCC) and Rates of Correct Classifications (RCC) for two (and three)-way classifications (Non-human vs. Human).

	Human vs. Non-human		**Human S vs. Human P vs. Non-human**		**Human P only vs. Non-human**	
RCC %	**All Antibiotic**	**Wilks' lambda (stepwise)**	**All Antibiotic**	**Wilks' lambda (stepwise)**	**All Antibiotic**	**Wilks' lambda (stepwise)**
ARCC	77.4	77.0	64.8	64.7	**85.7**	**86.8**
Non-human	83.3	83.4	68.8	70.4	**88.4**	**89.5**
Human	49.0	46.0				
Human - S			42.5	30.2		
Human - P			49.0	44.8	**57.9**	**58.9**
Cross-val. ARCC	75.6	76.6	62.7	64.0	**84.6**	**86.6**

Notes:

S=sewage line, P=portable toilet samples. "All antibiotic" indicates the analysis was conducted using all the antibiotics. "Wilks' lambda (Stepwise)" indicates that a stepwise method was used in which the program may remove some antibiotics from the analysis if they do not contribute to the classifications.

personnel who collected the samples noted that the line ran from an open-air vat, with high numbers of maggots and flies, close to an open field. Birds also had access to the material in the vats. These two sets of isolates were therefore separated and analyzed. When both human-sewage (Human S) and human-portable toilet (Human P) were included i.e. 3-way classification, the Human P group had a higher rate of correct classification (RCC) i.e. a larger proportion of the Human P classified as human than the Human S. The ARCC was lower as the classification was 3-way rather than 2-way (third and fourth column). When the Human S data was excluded, the ARCC increased to approximately 86%, non-human RCC to 89% and human to almost 60% (fifth and sixth columns), showing a good ability to discriminate between human and non-human isolates

9.3.2 FOUR-WAY CLASSIFICATION: HUMAN VS. WILDLIFE (BIRD/BAT) VS. LIVESTOCK (HORSE/COW) VS. PET (DOG)

Results of the statistical analyses for four way classification are shown in Table 9.7. Analyses were conducted with humans grouped together, separately, and without the sewage line samples. The highest ARCC was 50.8%, with only the human-P isolates included. Wildlife (birds with bats) had the highest RCC with 64% correctly classified, while pets (dog) isolates had the lowest RCC. This might be expected, as dogs interact with other animals and humans frequently and are thus exposed to multiple sources of *E. coli* strains. These groupings are not ideal as only limited animal sources are included in each group.

Table 9.7. Summary Table of Percent Average Rates of Correct Classification (ARCC) and Rates of Correct Classifications (RCC) for four-way classifications (Human vs. Wildlife vs. Livestock vs. Pet).

	Human vs. Non-human		**Human S vs. Human P vs. Non-human**		**Human P only vs. Non-human**	
RCC (%)	**All Antibiotic**	**Wilks' lambda (stepwise)**	**All Antibiotic**	**Wilks' lambda (stepwise)**	**All Antibiotic**	**Wilks' lambda (stepwise)**
ARCC	45.9	43.2	42.4	39.1	**50.8**	46.9
Wildlife	60.5	62.4	55.5	61.1	**64.0**	66.1
Livestock	40.1	33.2	35.3	26.0	**43.7**	35.3
Pet	39.6	34.8	39.6	34.1	**41.8**	35.2
Human	36.1	36.1				
Human-S			26.4	20.8		
Human-P			44.8	40.6	**47.4**	44.2
Cross-val. ARCC	43.4	42.6	38.8	38.5	**48.0**	45.5

Notes:
Human-P= human isolates from portable toilets only, Human-S=isolates from sewage line only. "All antibiotic" indicates the analysis was conducted using all the antibiotics. "Wilks' lambda (Stepwise)" indicates that a stepwise method was used in which the program may remove some antibiotics from the analysis if they do not contribute to the classifications.

9.3.3 SIX-WAY CLASSIFICATIONS: BIRD VS. COW VS. DOG VS. HORSE VS. BAT VS. HUMAN

Classification into multiple groups using ARA generally require large databases of several thousand isolates. If isolates were randomly assigned a source, 16.7% would be expected to fall into each category. Our RCCs show some ability to classify isolates correctly. As with the other groupings, use of only Human-P isolates improved the results compared with using all human isolates. An ARCC of approximately 40% was achieved for six-way classification.

9.3.4 ARA DISCUSSION

The rates of correct classification for human vs. non-human in this study are comparable with other studies e.g. Harwood et al. 2000, where their RCC for human was 69.3% and non-human was 78.4%. When only portable toilet samples were used for human the RCC in our study was almost 60% for human and non-human was 89%. Our ARCC for human vs. nonhuman, of approx. 86%, indicates good ability to classify human vs. non-human isolates correctly. Source tracking studies frequently place animals in groups such as wildlife etc. The greater the number of groups the lower the ARCC will become, as individual animals, or smaller groups are less likely to be identified correctly, due to similarities in certain variables i.e response to certain antibiotics may be similar between cow and dog compared with bat.

Results of cross-validation (also known as resubstitution analysis or leave-one-out method) are shown in the last row of Tables 9.6-9.8. Each isolate is removed one at a time and classified based on the library of remaining isolates. If these isolates classify, on average, as well as the library (labeled ARCC on the tables) the library can be considered representative. It can be

Table 9.8. Summary Table of Percent Average Rates of Correct Classification (ARCC) and Rates of Correct Classifications (RCC) for six-way classifications (Bird vs. Cow vs. Dog vs. Horse vs. Bat vs. Human).

	Human vs. Non-human		**Human S vs. Human P vs. Non-human**		**Human P only vs. Non-human**	
%	**All Antibiotic**	**Wilks' lambda (stepwise)**	**All Antibiotic**	**Wilks' lambda (stepwise)**	**All Antibiotic**	**Wilks' lambda (stepwise)**
ARCC	38.1	34.2	36.8	31.6	**39.9**	36.5
Bird	45.6	46.2	45.0	43.3	**45.6**	41.5
Cow	37.9	38.4	34.2	34.2	**36.5**	38.8
Dog	37.9	35.2	37.4	34.6	**37.4**	35.2
Horse	48.5	42.0	47.0	38.5	**45.0**	36.5
Bat	34.8	20.1	31.9	16.2	**35.3**	30.4
Human	25.2	25.2				
Human-S			16.0	11.3		
Human-P			39.6	39.6	**41.1**	37.9
Cross-val. ARCC	34.9	33.4	33.7	30.3	**37.3**	35.7

Notes:
Human-P= human isolates from portable toilets only, Human-S=isolates from sewage line only. "All antibiotic" indicates the analysis was conducted using all the antibiotics. "Wilks' lambda (Stepwise)" indicates that a stepwise method was used in which the program may remove some antibiotics from the analysis if they do not contribute to the classifications.

seen that for most of the analyses this is the case - the library ARCCs and cross-validation ARCCs are close.

The library compiled under this project meets many of the criteria for a viable library (Hagedorn, 2004). It is constructed from sources indigenous to the watershed being examined and includes isolates from numerous animals. The use of only a limited number of sources – those thought to be potential large contributors – will probably result in many unknown isolates not being classified - for example, wildlife was only represented by birds and bats. Bats were included as a separate group as the sanitary survey indicated they might be a major source due to their abundance under bridges in the area. There are temporal constraints as all samples were collected during the summer months. Seasonal changes e.g. migratory birds, cattle age etc. are therefore not considered. Wiggins et al. (2003) showed that new isolates classified well using a library a year old, and concluded that for ARA, using enterococcus, resistance patterns did not change appreciably over that time period.

The two distinct subgroups of 'human' samples found in our library, where many of the sewage sample isolates classified as non-human has been noted previously. Griffith et al. (2003) found that all of the quantitative methods compared in their study identified a high percentage (greater than 50% in some) of non-human material in their sewage effluent. This raises some issues in regard to ability to classify human vs. sewage sources.

Additional statistical analyses will be conducted prior to use of the library to identify sources of unknown isolates. The library will be tested for artificial clustering, determination of whether an unknown category should be used will be made, minimum detectable percentages will be calculated etc., as described by Hagedorn (2004). Frequency of misclassification for each source will also be used when identifying unknown source samples, as suggested by Harwood et al. (2000). This can be determined from the full tables, included in Appendix F, which show where the misclassified isolates from any category are grouped e.g. how many cows are classified as human vs. as dog etc. The library may be modified to remove isolates that classify with low probability and create an unknown category as suggested by Simmons et al. (2000). This will also improve the ARCCs.

Prior to use of the library the PFGE analyses will be super-imposed on the ARA library. Isolates used in PFGE will be compared with their classification using ARA. The ARA library will be used as a screening method, and PFGE will be used to confirm source identifications on a sub-set of the unknowns. This reduces cost and time compared with using a large PFGE library alone.

The Biolog™ database (carbon source utilization) will also be evaluated as a potential library for source discrimination, under a separate project. This may provide a complementary library for comparison purposes.

Recommendations:

- Before the library is used to classify unknown source samples, additional human samples should be added to the database. Further statistical analysis of the library may demonstrate other areas of the library needing additional isolates.
- Field collectors during year 2 need to re-assess potential sources of contamination, and if necessary additional sources should be added to the library.

9.4 SOURCE PULSE FIELD GEL ELECTROPHORESIS

Pulse field gel electrophoresis (PFGE) is a technique used as a molecular BST method that provides DNA fingerprints of sources of fecal bacterial contamination in a body of water. PFGE works with the entire DNA genome of *E. coli* strains. Developed commercially by Bio-Rad Laboratories, the PFGE technique was pioneered as a BST technique around 1994 by George Simmons, Ph.D., of Virginia Polytechnic Institute and State University and Stephen Edberg, Ph.D., of the Yale University School of Medicine. It uses restriction enzymes (NotI, in our case) to cut *E. coli* DNA at specific locations. The resulting segments are then run through electrophoresis to generate banding patterns that can be compared against a database of known patterns (see Appendix F for Gel Image).

This PFGE method is different from other approaches to electrophoresis. A specially designed gel setup, called the Contour-clamped Homogeneous Electric Fields (CHEF) apparatus, sends electric current through a gel in different directions for twenty hours, which allows for superior band separation. This technique employs a hexagonal array of electrodes that are clamped to a predetermined potential such that the electrical field encompassing the gel is comparable to that generated by two infinitely long electrodes. By employing a fixed reorientation angle of 120°and different pulse times, DNA molecules up to 2 Mb are resolved in mostly straight lanes across the gel. CHEF is the most versatile form of PFGE and can be used to separate DNA molecules up to 10 Mb in size. The success of the CHEF and other PFGE techniques is based, in part, on the concept that large DNA molecules undergo a major conformational change in response to an alteration of an electrical field vector that varies by >90°. This size-dependent separation found in PFGE is thought to be a function of the reorientation time. In other words, large DNA molecules take a longer time to re-orient in response to a change in the electrical field and hence spend a shorter portion of the pulse interval (the time that the electric field is applied in one direction) migrating through the gel.

Bacterial DNA analyzed through PFGE are embedded in agarose plugs. These plugs are placed in hollow combs of the electrophoresis gel, where they become part of the gel. Following electrophoresis, banding patterns become apparent after the gels are stained with ethidium bromide and are captured using a computer image documentation system with associated software. Embedding the DNA in agarose plugs essentially eliminates the potential for sample contamination, a common problem other with molecular BST approaches.

PFGE is a database-dependent methodology. Researchers use the method to examine isolates of bacterial sources from water samples and match the banding patterns with previously identified isolates stored in an established library. Because sources of bacterial contamination may vary from place to place, PFGE is location specific in terms of requiring isolate libraries to represent E. coli strains specific to each sampling region.

This project used Restriction Fragment Length fingerprinting to identify specific strains of indicator bacteria (I. e. *E. coli*) sources that were collected, isolated and cultured from selected animals. Total DNA was extracted from each culture, cut with a restriction enzyme (Not I), and fingerprinted by using Pulsed Field Gel Electrophoresis (PFGE). A library of electrophoretic DNA fingerprints of each source animal's *E. coli* bacteria was established for Buffalo and the Whiteoak Bayous area. The main product of this work, i.e. establishing a library of DNA fingerprints from major indicator strains associated with particular sources was completed. An image analysis system with associated software was used to preserve an image database of known sources of bacterial strains. This database will be used for the comparison and subsequent identification of unknown strains in later stages of the project.

9.4.1 MOLECULAR DATABASE

The bacterium, *E. coli*, was isolated from samples of fresh scat from six (6) sources (Table 9.1). DNA was extracted, cut with the restriction enzyme Not I, embedded in agarose, and fingerprinted using Pulse Field Gel Electrophoresis (PFGE) following the protocol as listed in the QAPP. The gels were stained and the gel was digitally computer captured using an image acquisition transilluminator with the 1-D Analysis software Quantity One®. Databases were created and managed with Diversity Database™. Samples from each known source (animal type) were optimized and added to the database. Bands were identified and sets were created for each organism. Data analyses were completed and reports generated.

Database construction began with a single gel image of each selected source. Building of the database continued as each image was evaluated by identifying and matching the unique bands in that gel called band types. Band types are used to link samples across gels. Each unique band type is defined by its position and molecular weight isoelectric point. Gel images (example in Appendix F) were added to the database and the list of band types increased. Every band in every gel in the database is identified as a particular band type. Band types are grouped together into band sets; a band set includes all the band types that were created using the same enzyme.

The gel images are linked to other gels by band sets within a database file. The database can undergo a variety of searching and population comparison tools to analyze the gel images in detail. The software (Diversity Database) supports single lane and multilane sample definition as well as phylogenetic tree analysis.

Database information is shown in Appendix F. Each animal has a unique set of bands for each of the lanes of restriction enzyme-cut DNA. The information in Appendix F includes the following:

1. A digital representation of the lane for the source organism with bands indicated as a bar and each numbered from top to bottom.

2. A graphic display that includes the band information with Background Subtracted. Background noise is removed from the lanes by a "Rolling disk" Method which refers to a hypothetical disk that follows the contour of a lane's profile trace, removing different intensities along the length of the lane. The amount of background removed is determined by the size of the disk chosen. A large disk will follow the profile trace less closely, touching fewer points along she trace and identifying less background. A smaller disk will more closely follow the profile trace, thus identifying more background. When the Rolling Disk background subtraction is applied, the lane trace display will change but the image will not reflect the change in background intensity. This is useful when only small amounts of DNA are present in a band and it would otherwise be difficult to discern by the human eye.

3. The Rf (Relative Front) method was used for locating the relative positions of bands in lanes. Relative front is calculated by dividing the distance a band has traveled down a lane by the length of lane (Follow Lane). This is useful if the gel image is curved or slanted. Bands in the gel image are marked with a dash at the center of the band. When a band is read, the average intensity value of each horizontal of pixels within the brackets is calculated. Next, the number of pixel rows between the top and bottom brackets is determined. Taken together, these result in an intensity profile for each of the bands.

Analysis of unknowns will be entered into the database for comparison. The type of results/ report will depend upon the initial evaluation. The software is powerful and multiple reports and analysis can be completed.

The 1-D Analysis Report will display all the advanced analysis data (including band types, normalized quantities, amount of sample loaded, etc.) for all the lanes on a gel image. The lanes will also be ranked in similarity to the lane initially selected to generate the report.

A search of samples in each database was completed using the Dice Coefficient Method. Searches may also be completed using the Jaccard Coefficient Method. Searches use one of two primary Search Strategies: lane similarity or band set membership. Similarity searches allow you to select a lane in a gel and specify the degree of similarity by which other lanes must match the lane you chose (i.e., at least 75% similar, 85% similar, etc.).

The Population and Image Report displays a series of lane diagrams of the population, sorted in an order of decreasing similarity from the reference sample for the similarity-searched populations. In addition, a Similarity Matrix can be produced for evaluation.

Phylogenetic trees are schematic representations of lane similarity. Cluster analysis produces different varieties of phylogenetic trees that are available in Diversity Database. Phylogenetic trees were computed and the numbers of clusters set were evaluated. The display is used as a visual indication of the compactness of each cluster and the dissimilarity of each cluster. Ward's method attempts to minimize the information by describing a set of N samples using a fewer number of clusters. Complete Linkage (also known as Furthest Neighbor or Maximum Methods) produces good algorithms for indicating outlier clusters. Both were generated for each data set to determine the number of clusters of closely matching sample bands.

The process of analysis of individual databases against a known of the same species is of little value but may reveal some information. The strength of the software is in its ability to link gels by band sets and analyze the data for the identification of unknown samples when compared to the known members of the database. The final database is built by either including all known samples or using only samples with unique or standard band sets (resubstitution). With small libraries, the correct classification of unknowns is relatively low; however, it increases as the number of known samples are included into the database. Wiggins et al. (2003) reported that analysis will work faster if all samples are included, not just those with unique patterns although the differences may not be too substantial. Among papers published to date with molecular (PFGE) methods, most have built a library of unique patterns for each known sample type in the database.

PFGE is the standard against which other methods are compared in many epidemiological investigations. It should be noted that in practice, 100% correct classification rates are almost never observed, particularly in large libraries; however, correct classification rates ranging from >80% to less than 50% have proved to be useful for watershed analysis. With small libraries (100), classification rates may near only 25-27% of new samples run against the database (Wiggins et al. 2003). Even small bodies of water will require 1,200 to 1,500 isolates at a minimum to satisfy the needs of the procedure. The greater the geographical area, the greater the diversity of strains that will be found from the source samples and the greater number of samples will be required to achieve an acceptable levels of correct classification. It is also important to periodically add new known samples over the duration of the project to be sure that the acceptable level for each source is being maintained over time and may be a measure of temporal stability (Dombek et al. 2000; Wiggins et al. 2003).

Simmons et al. (2000) proposed and used 80% as a cutoff, and removed all isolates from his library that were classified below that level. With this approach, nearly one half of the isolates were removed. If a high proportion of the water sample isolates are consistently placed in the unknown category, then it is an indication that the library is not representative of the body of water (Hagedorn et al. 2003).

Demanding methods such as PFGE require a person with a high level of skill and experience to make the method work correctly on a routine basis and to process the necessary number of isolates required. The data should not be used as a tool to estimate animal population densities or numbers, but can be an excellent method to identify those animals that have a local impact on water quality (Simmons et al. 2000). Similarity measures using Dice Coefficient and resulting Cladistical Analysis (Complete Linkage and Ward's Method) were used to evaluate the database.

9.5 UNKNOWN SOURCE SAMPLING

A single set of samples from the watershed was collected by University of Houston personnel 8/3/04. Samples were shipped overnight to Texas A&M University-Corpus Christi for analysis, received on 8/4/04. For each site two bottles of water and two of sediment were collected. The sites were identified on the Chain of Custody forms as follows:

- Site #2:WWTP upstream
- Site #7: commercial
- Site #1: no WWTP upstream
- Site #3: residential

For each water sample varying volumes (10, 30, and 100 ml) were filtered onto 0.45 micrometer cellulose nitrose filters. As concentrations of bacteria were unknown, different volumes were utilized to ensure filters with individual colonies were obtained from which isolates could be transferred. Filters were placed onto mTEC agar plates, incubated, transferred and verified using the MicroLog™ Microbial Identification System as previously described for known source isolates. Sediment samples (40g) were suspended in 400 ml of fecal coliform dilution water and placed onto a shaker for 45 minutes. The supernatant was then removed and filtered, as for the water samples except volumes of 0.1, 0.3 and 1 ml were used. The remaining steps followed those for known source isolates. At least 50 isolates were obtained from each site for both water and sediment samples and stored on Tryptic Soy Agar (TSA) slants (Table 9.9). Isolates were then cryofreezed in duplicate and stored at -70^{o}C for further analysis in year 2. MicroLog MIS data is stored on the enclosed CD-ROM, under the folder "Hou Biolog unknowns".

The current status of the project is that the isolates described above have been confirmed and stored. These isolates still need to be analyzed by ARA and PFGE, and then compared to the database (library) of knowns for source identification.

Table 9.9 Numbers of *E. coli* isolates obtained and verified, for analysis Year 2.

Site Number	Matrix	# Isolates Stored	# Isolates Confirmed by MIS
1	sediment	50	40
	water	50	48
2	sediment	50	40
	water	50	43
3	sediment	54	51
	water	50	40
7	sediment	50	44
	water	50	37
TOTAL		404	343

CHAPTER 10

HSPF MODEL EXPANSION

This chapter provides a summary of work that has been completed on the two models that have been developed for Buffalo and Whiteoak Bayous. Two Hydrologic Simulation Program - Fortran (HSPF) water quality models were developed for Buffalo and Whiteoak Bayous to simulate *E. coli* concentrations. The models were developed under Work Order 2 and were revised under Work Order 5. Three primary tasks are described in this chapter. The first task involved refining the existing modeling of point sources using time-varying flow and concentrations. For this task, the point source flow inputs to the models varied with time as opposed to the constant self-reported average flows and permitted flows that were included in the Work Order 5 HSPF models. Concentrations also varied with time using the "peak" and "off-peak" EC concentrations measured as part of Work Order 2. This task is described in Section 10.1.

The second task involved expanding the HSPF TMDL model for Buffalo Bayou to include areas above Addicks and Barker reservoirs. The main goal of this task was to include the upper Buffalo Bayou watershed, explicitly modeling the effect of solids and bacteria settling produced by the two impoundments. Historical data indicate that significant bacteria loads are coming from the area, however, the modeling effort to date includes discharge and bacteria loadings from the two reservoirs as point source inputs. This model expansion is described in Section 10.3.

During the process of the model expansion, the modeling period was shifted from 1999-2001 to 2001-2003 and a calibration/validation approach was utilized. Calibration was conducted from January 1, 2001 through September 30, 2002. Validation was undertaken from October 1, 2002 to September 30, 2003. The modeling period was shifted to allow calibration of the model to actual EC data, rather than the converted EC data used during the modeling conducted in Work Orders 2 and 5. Until recently, there was not enough data to justify making the change from the old modeling period to one that included true EC values. A new set of data was collected for the new modeling period and data for this task are presented in Section 10.2.

The resulting models (with shifted time periods and expanded domains) were calibrated using time-varying WWTP flows and the EC data compiled from 2001 to 2003. The results of the calibration are presented in Sections 10.3 and 10.4 for Buffalo and Whiteoak Bayous, respectively.

10.1 WWTP TIME-VARYING FLOW

In the absence of rain, waste water treatment plant (WWTP) discharges comprise the majority of the flow in Whiteoak and Buffalo Bayous. Therefore, to predict water at low-flow in the two bayous, it is necessary to correctly predict the WWTP outflows.

The model developed in Work Order 2 used the five-year average WWTP flows from the years 1997-2001 as a basis to predict flows in the bayous. In order to refine these point sources, an analysis of the actual flow data from WWTPs was undertaken. Of the 152 WWTPs in Whiteoak and Buffalo bayous, only the six City of Houston (COH) plants keep automated information about their discharge flows on an hourly basis. The other 146 plants do not keep automated hourly flow records, as records are usually noted by hand in a daily log. After an analysis of the five year data, presented in Work Order 6, Quarterly Report 2, it was determined that current daily, monthly and/or hourly flows from the City of Houston should be obtained for analysis of flow patterns.

The goal of this section is to explore the possibility of using the six COH WWTP discharge flows, which have been automatically collected, to create a flow pattern that could be applied to the other 146 WWTPs in the HSPF model.

10.1.1 SUMMARY OF CITY OF HOUSTON WWTP DAILY DISCHARGE FLOWS

In order to incorporate hourly flow into HSPF, flow data for all six City of Houston (COH) waste water treatment plants (WWTPs) were obtained from the City of Houston. These plants are split evenly between Buffalo and Whiteoak bayous; with Whiteoak, Northwest, and Westway plants located in Whiteoak Bayou, and Turkey Creek, West District, and Park Ten plants located in Buffalo Bayou.

The Supervisory Control and Data Acquisition (SCADA) daily and hourly data from the six City of Houston WWTPs were obtained and will be characterized here. Hourly data for the Northwest and Park Ten plants were analyzed for hourly flow patterns. Daily flow data for all plants were analyzed, and all data were checked for normality.

Figure 10.1.1 contains graphs of the daily flow data for the six plants. The flow data are represented by a dark blue line, the dashed blue line represents the 1997-2001 five-year average flow. The pink line represents the 2001-2003 three-year average flow, the green line illustrates the self-reported monthly averages for the plants, and the yellow line represents the permitted flow for each plant. It is of note that the average flows for Northwest and West District plants have remained unchanged for the past eight years, indicated by the fact that the three-year average and the five-year average are equivalent. The average flow at all other plants has increased for this three year period when compared to the average for the prior 5 years. Considering that 2001 was one of the wettest years on record, rainfall may have the influenced the three-year averages upward to some extent. It can be seen that the average flow at all plants is well below the permitted flows for the plants, except for high flow events. These high flow events do not point to an obvious pattern or seasonal variation in the data.

There are some anomalies at Park Ten which should be discussed here. It appears that the Park Ten plant did not include some hourly high flow readings in their self-reported monthly average. Looking at the end of 2002, in Figure 10.1.1, it can be seen that the monthly average flow (in green) does not increase as a result of the high flow events shown in navy blue. The reason behind this inconsistency has been reported as a possible high flow event in the bayou which may have backed water up into the plant. This back-flow probably raised the level of water used for flow readings, and the high flow points in question were then ignored for the purposes of calculating the monthly average flow.

A brief summary of the data can be found in Table 10.1.1 which shows the high, low, median, average three year flow, geometric mean, and standard deviation of flow for each plant. There is a broad range of flows, as illustrated in Table 10.1.1. Looking at the difference between the average to low flow compared with the average to high flow events, it is necessary to examine the normality of the data. Furthermore, the standard deviation in the data is huge, which also leads to the conclusion that the data may not be normal and may in fact exhibit no patterns.

In order to conduct a more complete analysis of the data, a normal distribution must be established. This is important because many statistical tests assume normality. If this assumption is not met, then the results of the test may not be valid.

Figure 10.1.1 Daily Flows at City of Houston Plants

Table 10.1.1
Summary Statistics for Daily Flow at City of Houston WWTPs for 2001 to 2004 (in MGD)

	10495-135 Park Ten	10495-076 Northwest	10498-030 West District	10495-109 Turkey Creek	10495-139 Westway	10495-099 Whiteoak
2001-2003 Avg Flow	0.61	9.56	9.58	4.53	0.52	1.79
1997-2001 Avg Flow	0.44	9.52	9.74	4.18	0.45	1.52
Median Flow	0.57	8.26	8.92	4.44	0.49	1.72
Geometric Mean Flow	0.58	8.90	9.25	4.41	0.51	1.74
Minimum Flow	0.23	1.99	4.46	0.46	0.25	0.42
Maximum Flow	8.46	59.84	50.00	15.00	2.19	6.02
Permitted Flow	3.50	18.00	26.40	12.00	1.00	4.00

Normality was tested by graphing the quantile-quantile plots (QQ) of the data using SPLUS statistics package. A QQ-plot is a scatter-plot created by plotting the standardized data set values against the expected values for the data if they were normally distributed (using the same mean, standard deviation, and sample number). The result would follow the normal line on the graph if the data were perfectly normal. Figure 10.1.2 shows the results of this test for all plants. Note that the data are not normally distributed as defined above. Therefore, a log-transformation was performed to bring the data closer to a normal distribution. To calculate a log-transformation, the natural log of all flows were calculated and used as the data set. The results were again checked using QQ-plots, and it can be seen in Figure 10.1.3 that the data were much closer to the normal distribution after the transformation.

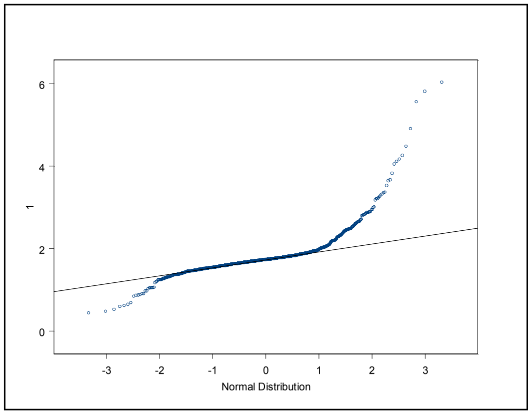
10.1.2 DEVELOPMENT OF CONVERSION FACTORS

Using the daily and hourly flows from the six plants, the goal was to find a temporal relationship common to all six WWTPs, and use that as a model of flow variation for all WWTPs in Buffalo and Whiteoak Bayous. However, after using autocorrelation to check for patterns within the data, the Runs tests to check for randomness in the data, and regressions of WWTP flow to rain data, it was determined that another method to develop a time series must be employed. For explanations of these statistical tests and their results, please see Appendix G.

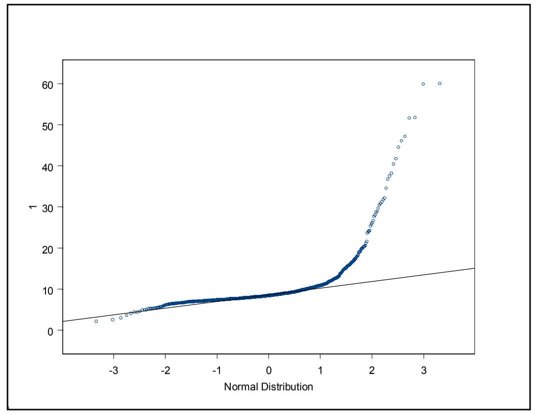
Therefore, in order to accomplish the goal of time varying flow inputs to the HSPF model, hourly conversion factors were developed from one of the two plants for which hourly data were obtained, Northwest District (WQ0010495-076). The hourly flow from Park Ten was not used because the majority of the plant inflow is from office buildings and other industrial-type sources that exhibit different flow patterns that most other plants in the watersheds. Hourly

QQ-normal Plots of Non-Transformed Whiteoak Bayou Wastewater Treatment Plant Flows

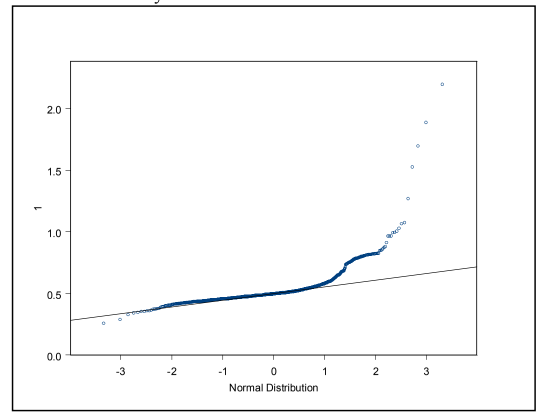
Whiteoak Non-Transformed Flow Data



Northwest Non-Transformed Flow Data

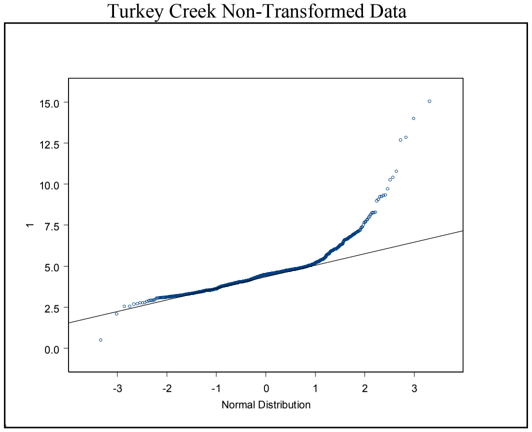


Westway Non-Transformed SCADA Flows

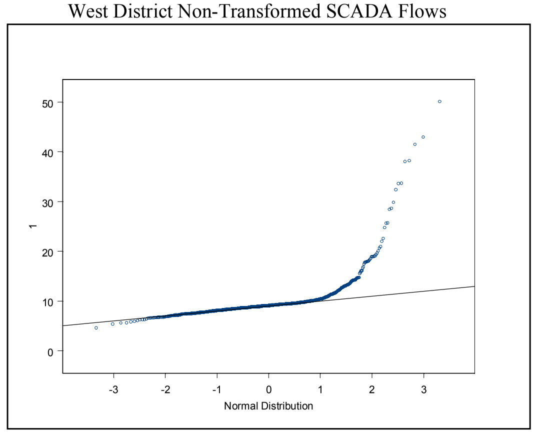


QQ-normal Plots of Non-Transformed Buffalo Bayou Wastewater Treatment Plant Flows

Turkey Creek Non-Transformed Data



West District Non-Transformed SCADA Flows



Park Ten Non-Transformed Flows

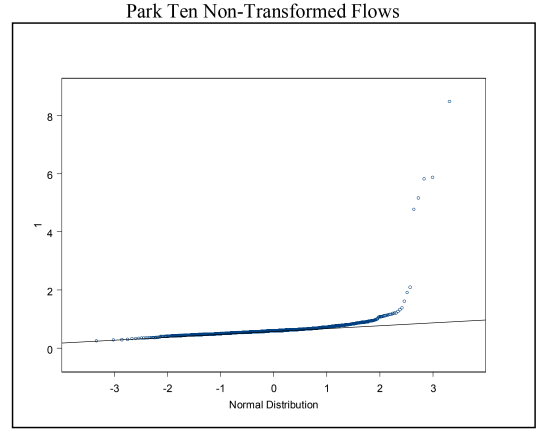
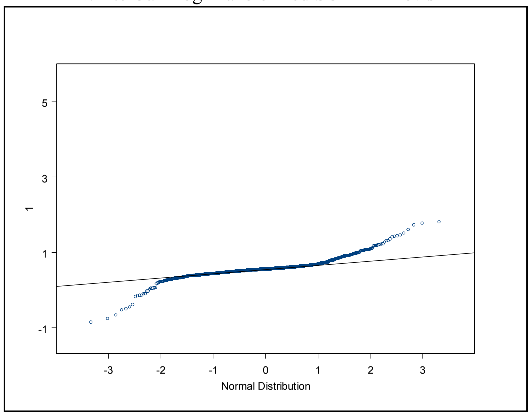


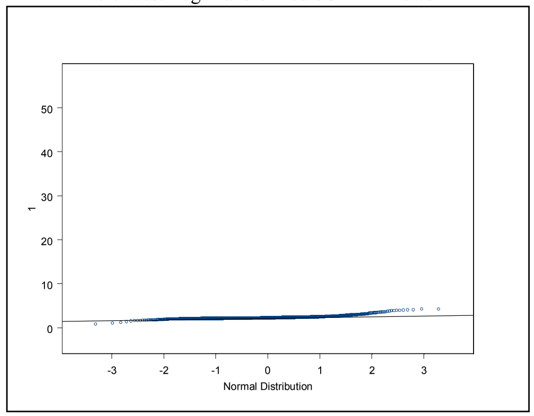
Figure 10.1.2 QQ-normal plots of non-transformed flow data

QQ-normal Plots of Transformed Whiteoak Bayou Wastewater Treatment Plant Flows

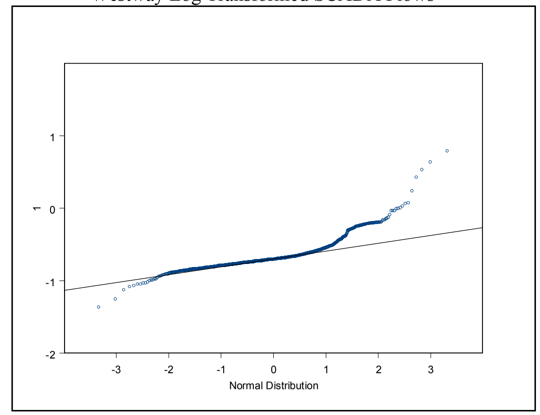
White Oak Log Transformed SCADA Flows



Northwest Log Transformed SCADA Flows

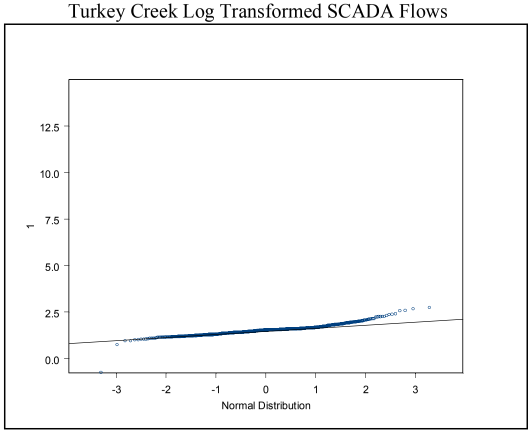


Westway Log Transformed SCADA Flows

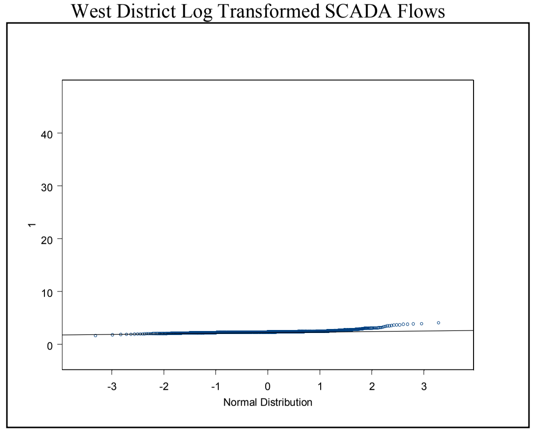


QQ-normal Plots of Log-Transformed Buffalo Bayou Wastewater Treatment Plant Flows

Turkey Creek Log Transformed SCADA Flows



West District Log Transformed SCADA Flows



Park Ten Log Transformed SCADA Flows

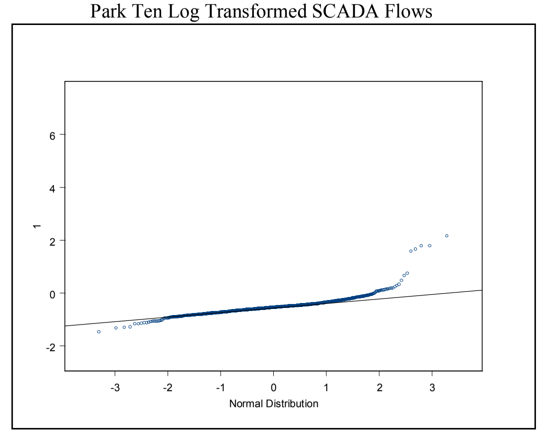


Figure 10.1.3 QQ-normal plots of log-transformed WWTP flow data

inputs to the HSPF model were required to better predict water flows in Whiteoak and Buffalo Bayous.

Based on the analysis presented in Quarterly Report 3, patterns for weekend and weekday flows were different for the year 2003 at the Northwest District WWTP. The average flow for weekdays was higher than the average flow for weekends. A t-test comparing the difference between the means of the weekend and weekday data sets was completed, with a resulting p-value of less than 0.05 indicating that the weekday and weekend means were statistically different.

Conversion factors were developed utilizing the Super Smoother function in the SPLUS statistical program to obtain weighted averages for the monthly average flow by hour, as explained in WO6 Quarterly Report 3. For example, for the hour 0 (midnight to 1am), the Super Smoother function calculated a weighted average of the 0-hour hourly flow for the entire month. This was then divided by the average monthly flow for the plant so that the factor could be applied to other plants. This procedure was completed for all hours and all months of the year 2003. Tables 10.1.2 and 10.1.3 show the conversion factors obtained from each hour flow divided by the monthly average. Peak factors are highlighted in grey, and off-peak conversion factors are in white.

The conversion factors were applied to the two data sets from Northwest District WWTP as follows. According to Figure 10.1.4, it appears that there are two peak flows and two low flows each day for hourly flow from WWTP Northwest District. The beginning of these peaks occurred at roughly 6am and 6pm. After calculation of conversion factors, the conversion factors were averaged to obtain four coefficients for weekdays and four for weekends. These were termed peak and off-peak flows. The peak conversion factor was applied to all time periods from

Table 10.1.2
Weekday Flow Conversion Factors (MGD/average monthly MGD

Northwest District													
Hour	January	February	March	April	May	June	July	August	September	October	November	December	Yearly Avg
0	1.367	1.219	1.306	1.401	1.384	1.280	1.319	1.217	1.261	1.325	1.361	1.349	0.870
1	1.104	1.039	1.135	1.288	1.354	1.239	1.276	1.183	1.178	1.190	1.099	1.101	
2	0.877	0.888	0.942	0.994	1.039	1.001	1.024	0.910	0.898	0.902	0.866	0.871	
3	0.760	0.740	0.783	0.776	0.771	0.776	0.787	0.660	0.692	0.662	0.694	0.720	
4	0.621	0.686	0.705	0.636	0.585	0.620	0.641	0.557	0.620	0.613	0.587	0.606	
5	0.582	0.655	0.651	0.550	0.508	0.512	0.542	0.453	0.595	0.566	0.522	0.529	
6	0.575	0.652	0.634	0.516	0.473	0.487	0.501	0.424	0.552	0.510	0.463	0.508	1.019
7	0.640	0.692	0.687	0.572	0.511	0.499	0.515	0.456	0.596	0.548	0.507	0.532	
8	0.779	0.800	0.836	0.762	0.726	0.658	0.631	0.620	0.810	0.807	0.705	0.690	
9	0.975	0.998	1.018	1.011	0.978	0.916	0.854	0.857	1.064	1.053	1.034	0.932	
10	1.063	1.066	1.114	1.091	1.112	1.068	0.978	0.923	1.083	1.131	1.132	1.095	
11	1.189	1.171	1.102	1.082	1.068	1.074	0.997	0.907	1.089	1.122	1.142	1.088	
12	1.153	1.150	1.192	1.134	1.094	1.149	1.058	0.913	1.070	1.098	1.189	1.175	1.058
13	1.093	1.085	1.167	1.229	1.207	1.282	1.227	1.048	1.165	1.179	1.181	1.152	
14	1.071	1.069	1.109	1.118	1.101	1.215	1.187	0.992	1.085	1.115	1.113	1.104	
15	1.057	1.044	1.083	1.109	1.110	1.157	1.174	0.973	1.047	1.050	1.106	1.078	
16	1.056	1.015	1.048	1.041	1.028	1.145	1.167	0.929	1.044	0.998	1.063	1.040	
17	1.053	0.996	1.031	1.023	1.024	1.088	1.153	0.957	1.034	0.980	1.078	1.098	
18	1.078	1.018	1.053	1.063	1.031	1.116	1.185	0.971	1.065	1.018	1.089	1.123	1.081
19	1.120	1.033	1.052	1.089	1.107	1.129	1.232	1.039	1.134	1.084	1.119	1.144	
20	1.189	1.086	1.093	1.140	1.151	1.165	1.279	1.109	1.182	1.143	1.216	1.209	
21	1.215	1.129	1.149	1.206	1.203	1.205	1.261	1.141	1.233	1.219	1.257	1.261	
22	1.252	1.154	1.187	1.257	1.257	1.261	1.293	1.188	1.264	1.300	1.271	1.243	
23	1.335	1.227	1.196	1.283	1.325	1.237	1.305	1.195	1.287	1.283	1.238	1.219	

Table 10.1.3
Weekend Flow Conversion Factors (MGD/average monthly MGD)

Northwest District													
Hour	January	February	March	April	May	June	July	August	September	October	November	December	Yearly Avg
0	1.114	1.132	1.174	1.131	1.175	1.301	1.129	1.079	0.934	1.012	1.197	1.076	0.891
1	0.956	1.037	1.019	1.132	1.250	1.273	1.127	1.077	0.970	1.051	0.978	0.994	
2	0.810	0.911	0.894	0.929	1.020	0.995	0.969	0.873	0.915	0.991	0.806	0.912	
3	0.682	0.811	0.770	0.766	0.822	0.827	0.780	0.708	0.769	0.833	0.684	0.826	
4	0.610	0.730	0.702	0.638	0.677	0.687	0.647	0.565	0.614	0.665	0.613	0.759	
5	0.572	0.690	0.649	0.557	0.547	0.575	0.556	0.495	0.542	0.588	0.539	0.680	
6	0.506	0.632	0.590	0.520	0.498	0.519	0.486	0.450	0.510	0.553	0.484	0.608	0.826
7	0.480	0.750	0.586	0.484	0.498	0.485	0.480	0.400	0.479	0.519	0.453	0.571	
8	0.564	0.829	0.669	0.517	0.533	0.520	0.508	0.439	0.515	0.559	0.513	0.564	
9	0.684	0.841	0.769	0.682	0.600	0.621	0.609	0.530	0.629	0.682	0.652	0.709	
10	0.871	0.898	0.930	0.848	0.817	0.839	0.755	0.704	0.885	0.959	0.870	0.936	
11	1.157	1.096	1.134	1.013	1.061	1.035	0.900	0.870	1.022	1.107	1.096	1.130	
12	1.206	1.243	1.277	1.154	1.233	1.174	1.095	1.027	1.185	1.285	1.347	1.379	1.094
13	1.213	1.221	1.234	1.327	1.443	1.388	1.257	1.203	1.296	1.404	1.315	1.334	
14	1.203	1.206	1.195	1.247	1.363	1.250	1.206	1.126	1.213	1.315	1.279	1.282	
15	1.184	1.190	1.174	1.163	1.217	1.205	1.105	1.062	1.193	1.293	1.268	1.217	
16	1.172	1.170	1.141	1.098	1.149	1.138	1.104	1.031	1.121	1.215	1.257	1.151	
17	1.175	1.191	1.111	1.109	1.108	1.078	1.077	0.983	1.063	1.152	1.228	1.166	
18	1.190	1.159	1.099	1.086	1.104	1.065	1.047	1.029	1.029	1.115	1.251	1.153	1.175
19	1.213	1.150	1.062	1.066	1.099	1.051	1.052	1.050	1.017	1.102	1.210	1.156	
20	1.232	1.204	1.101	1.069	1.123	1.072	1.061	1.127	1.030	1.116	1.203	1.184	
21	1.246	1.196	1.114	1.100	1.087	1.068	1.036	1.151	1.067	1.157	1.207	1.191	
22	1.248	1.168	1.143	1.135	1.174	1.088	1.080	1.122	1.113	1.206	1.190	1.186	
23	1.248	1.229	1.141	1.156	1.165	1.118	1.121	1.134	1.142	1.238	1.110	1.152	

Peak | Off-Peak

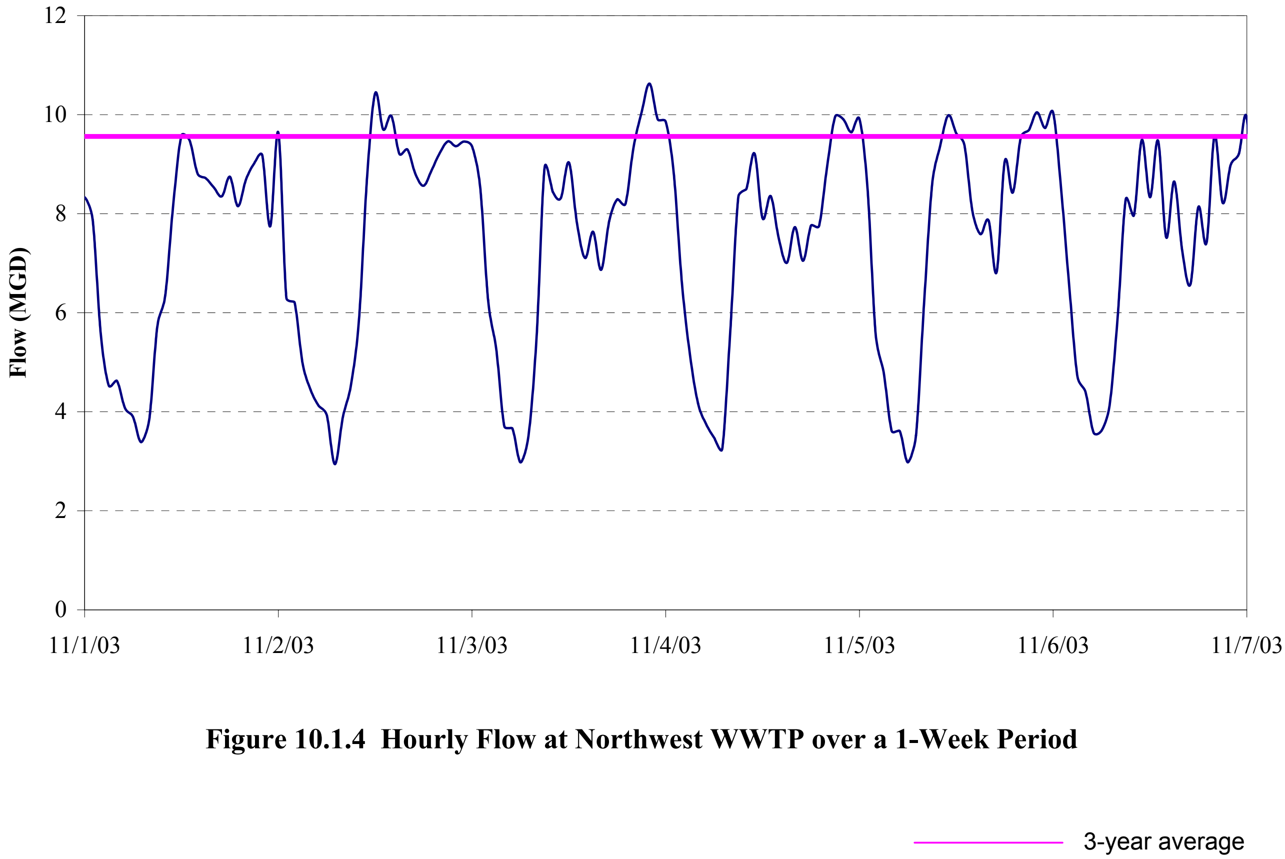


Figure 10.1.4 Hourly Flow at Northwest WWTP over a 1-Week Period

12am to 6am and 12pm to 6pm. Off-peak conversion factors were applied to the remaining hours.

10.1.3 USE OF CONVERSION FACTORS TO DEVELOP TIME SERIES

The HSPF model requires hourly input, and discussed in the previous section, varying the input about the self-reported monthly mean using the six-hour step conversions allowed the development of hourly flow data for treatment plants. These conversions were applied to the monthly average flow at 146 plants in both Buffalo and White Oak bayous using Microsoft Excel. If there was a rainfall event of over 0.10 inches on that day near the WWTP, as indicated by using the rain gauge data for the closest gauge, then the flow was increased by 10%. The results for all plants can be found in Appendix H.

For plants that had more specific data (i.e., the six COH plants), the most specific data was used to input to the model. For Northwest and Park Ten hourly flows were used, and daily flows were used for the remaining four COH plants.

To develop inputs into HSPF, the conversion factors were applied to each WWTP that had self-reporting data. Flows from plants within the same watershed were summed together to generate a single flow input for each subwatershed. EC loads associated with the plants were developed by using the calculated time-varying flows and site specific information that was collected during 2001, if available. If site specific data for the peak and off-peak EC concentrations were not available, then the average for the subbasin was used for the plant instead. Also, if there was a single plant in a watershed without EC data or all plants in the subwatershed were not sampled, then the average peak and off-peak concentrations for the entire watershed were used instead.

10.1.5 ANALYSIS OF TIME-VARYING FLOW (TVF) OUTPUTS

The resulting time series that were developed using the conversion factors were assessed to determine: (1) how well they represent the reported data and (2) how they represent the overall volumes of water that are discharged to the Buffalo and Whiteoak Bayou watersheds. These two different assessments will be discussed in the following section.

Figure 10.1.5 presents a comparison of the reported daily average flows with the daily average of the predicted TVFs. The daily averages of the TVFs are quite constant in comparison with the actual daily averages. There are some small increases in TVF daily averages, which are a result of the 10% increment used for days when precipitation was greater than 0.1 in. These small increases do not reproduce the major peaks in the reported flow that are observed on some days. The differences between the predicted TVF and actual reported daily average flows were quantified using a regression analysis, the results of which are presented in Table 10.1.4. The r^2 values for the regression range from 0.114 to 0.366, an indication that the predicted TVF data does not account for all the variability present in the flow data. In addition, the data presented in Figure 10.1.5 were totaled over the period from 3/1/2001 to 11/30/2003 and the results are presented in Table 10.1.5. The total volumes estimated by the TVF appear to match the daily flows reported by the COH plants well.

The WWTP 5-year self-reported averages that were employed in the HSPF Work Order 5 model were compared to the predicted WWTP TVF using daily flows from the COH WWTPs and also on a subwatershed basis. The results of this comparison are presented in Table 10.1.6. The total volume discharged from 1/1/2001 to 9/30/2003 was calculated for the 5-year average by multiplying the constant 5-year average flow by the total number of hours (24,072) during the modeling period. The average of the predicted time-varying flow time series was calculated from

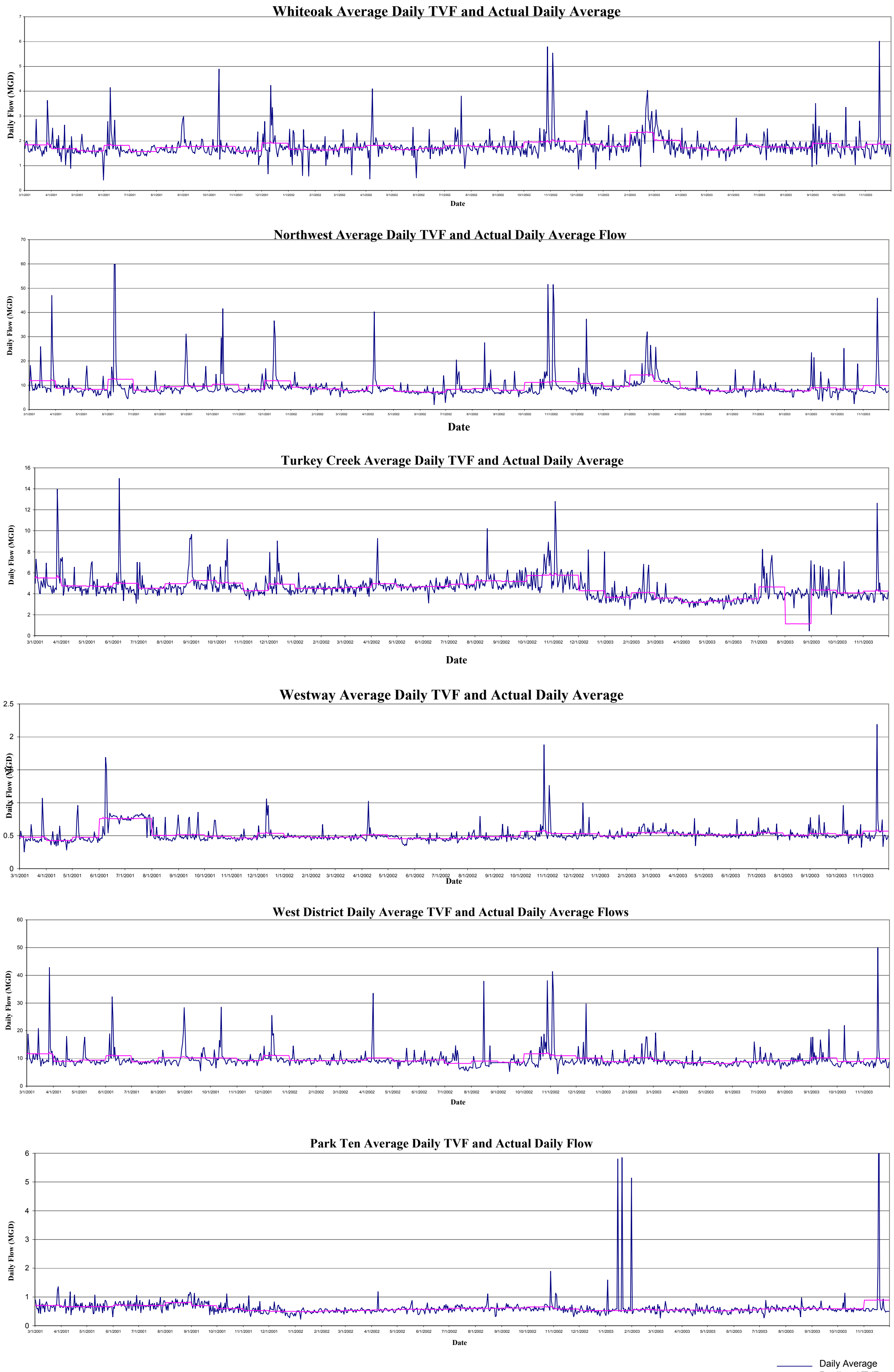


Figure 10.1.5 Comparison of Actual and Predicted TVF Daily Averages for Six City of Houston Plants

Table 10.1.4 Regression Analysis of TVF to Observed Daily Averages

Plant	Permit Number	R^2	p-value
WHITEOAK	10495-099	0.114	0.000
NORTHWEST	10495-076	0.168	0.000
TURKEY CREEK	10495-109	0.281	0.000
WESTWAY	10495-139	0.366	0.000
WEST DISTRICT	10495-030	0.118	0.000
PARK TEN	10495-135	0.135	0.000

Table 10.1.5 Comparison of Daily Volumes from City of Houston Plants to Volumes Estimated by TVF

Plant	Permit Number	Observed	TVF
WHITEOAK	10495-099	1791.3	1793.6
NORTHWEST	10495-076	9451.6	9465.9
TURKEY CREEK	10495-109	4582.8	4502.4
WESTWAY	10495-139	521.9	521.8
WEST DISTRICT	10495-030	9644.3	9658.7
PARK TEN	10495-135	621.7	605.4

Table 10.1.6 Comparison of WWTP 5-year Average Self-reported Flows and TVFs

Watershed	Subwatershed	Self-Reported Flow		Time Varying Flow		Difference
		5-Year Average	Total Volume	Average	Total Volume	in Total Volume
Whiteoak	1	0.0502	1208.4	0.0655	1576.8	-30%
	2	1.1600	27923.5	1.2748	30687.8	-10%
	4	0.3760	9051.1	0.3947	9500.7	-5%
	7	0.1810	4357.0	2.2364	53835.8	-1136%
	9	0.1920	4621.8	0.0260	625.6	86%
	10	0.3030	7293.8	0.2680	6450.5	12%
	11	0.1280	3081.2	0.1473	3545.2	-15%
	13	0.2190	5271.8	0.2328	5605.0	-6%
	17	0.0157	377.9	0.0212	509.5	-35%
	33	1.1800	28405.0	1.2380	29801.4	-5%
	35	0.2762	6649.7	0.1301	3132.1	53%
	37	0.1000	2407.2	0.0000	0.0	100%
	40	0.0192	462.2	0.0098	235.2	49%
	42	0.0213	512.7	0.0054	129.4	75%
	44	0.0001	2.3	0.0001	1.5	34%
	Total		101625.6		145636.6	-43%
Lower Buffalo	53	0.2880	6932.7	0.3721	8956.7	-29%
	55	0.4570	11000.9	0.5903	14210.1	-29%
	56	0.0227	546.4	0.0203	488.0	11%
	Total		18480.1		23654.8	-28%
Addicks Reservoir	103	0.0006	14.3	0.0000	0.0	100%
	104	0.0025	59.7	0.0011	27.3	54%
	105	0.0159	382.7	0.0081	195.9	49%
	106	0.2940	7077.2	0.3417	8225.1	-16%
	108	0.1430	3442.3	0.1320	3178.7	8%
	109	0.0508	1222.9	0.0585	1407.1	-15%
	110	0.3280	7895.6	0.1243	2991.4	62%
	113	0.3890	9364.0	0.4153	9996.3	-7%
	114	0.0154	370.7	0.0277	666.6	-80%
	115	0.0310	746.2	0.0841	2025.0	-171%
	116	0.0097	233.5	0.0375	902.7	-287%
	117	0.0318	765.5	0.0439	1056.8	-38%
	119	0.0335	806.4	0.0508	1222.6	-52%
	120	0.0135	325.0	0.0348	837.6	-158%
	122	0.0010	23.4	0.0088	211.6	-804%
	123	0.0122	293.7	0.0175	421.4	-44%
	124	0.0861	2072.6	0.1059	2550.0	-23%
	125	0.0681	1639.3	0.0951	2288.6	-40%
	126	0.0287	690.9	0.0484	1165.4	-69%
	131	0.0802	1930.6	0.0839	2020.4	-5%
	Total		39356.4		41390.5	-5%

Watershed	Subwatershed	Self-Reported Flow		Time Varying Flow		Difference
		5-Year Average	Total Volume	Average	Total Volume	in Total Volume
Barker Reservoir	133	0.1050	2527.6	0.2081	5008.8	-98%
	134	0.0093	224.8	0.0119	286.4	-27%
	135	0.0194	467.0	0.0343	825.7	-77%
	136	0.1400	3370.1	0.1463	3521.1	-4%
	145	0.0005	11.0	0.0011	26.8	-143%
	146	0.0146	351.5	0.0198	476.6	-36%
	147	0.0503	1210.8	0.0575	1385.2	-14%
	148	0.0701	1687.4	0.0689	1657.9	2%
	149	0.0601	1446.7	0.0783	1884.9	-30%
	150	0.0968	2330.2	0.0000	0.0	100%
	153	0.2070	4982.9	0.1954	4702.6	6%
	155	0.1640	3947.8	0.1796	4322.7	-9%
	Total		22557.8		24098.8	-7%

Notes:
All flows in acre-ft/hr
Self-reported Flow is the average from 1997-2001 of Self-reported data, assumed as constant value
TVF is the flow predicted using conversion factors, average is average of predicted time series
Averages and volumes calculated over time period from 1/1/01 to 9/30/03
Difference calculated as (TVF-5 year Average)/5-year Average

1/1/2001 to 9/30/2003. The total volume is the sum of the hourly predicted flows from 1/1/2001 to 9/30/2003.

The table demonstrates that generally, the time varying flows provide a slightly higher volume of water when compared with the 5-year self-reported average flow. The results in this table indicate that the method developed to simulate time-varying flows provides a reasonable match to the 5-year average, as the values are relatively close. Differences in volumes at the subwatershed level vary from -1136% to 100%, while on the watershed level the differences are much smaller. The difference between the two volumes range from 5% in Addicks Reservoir to 43% in the Whiteoak Bayou watershed.

10.2 DATA COLLECTION FOR NEW MODEL TIME PERIOD

In order to set up the Whiteoak and Buffalo Bayou HSPF models for the period from 2001 to 2003, several pieces of information were required including rainfall data, evapotranspiration data, evaporation data, observed flows and observed EC concentrations. These data were gathered and are presented in the following sections, with data required to set up the model presented in Section 10.2.1 and data used for calibration purposes in Section 10.2.2.

10.2.1 MODEL SET-UP DATA

Precipitation data were obtained from the City of Houston for rain gauges 14, 21, 30, 32, 34, and 35. The data that were acquired for the new time period are presented in Figure 10.2.1 and the rain gauge locations are shown in Figure 10.2.2. The rainfall during the validation period averaged 66 inches for 2001, 43 inches in 2002 and 39 inches in 2003. Hourly potential

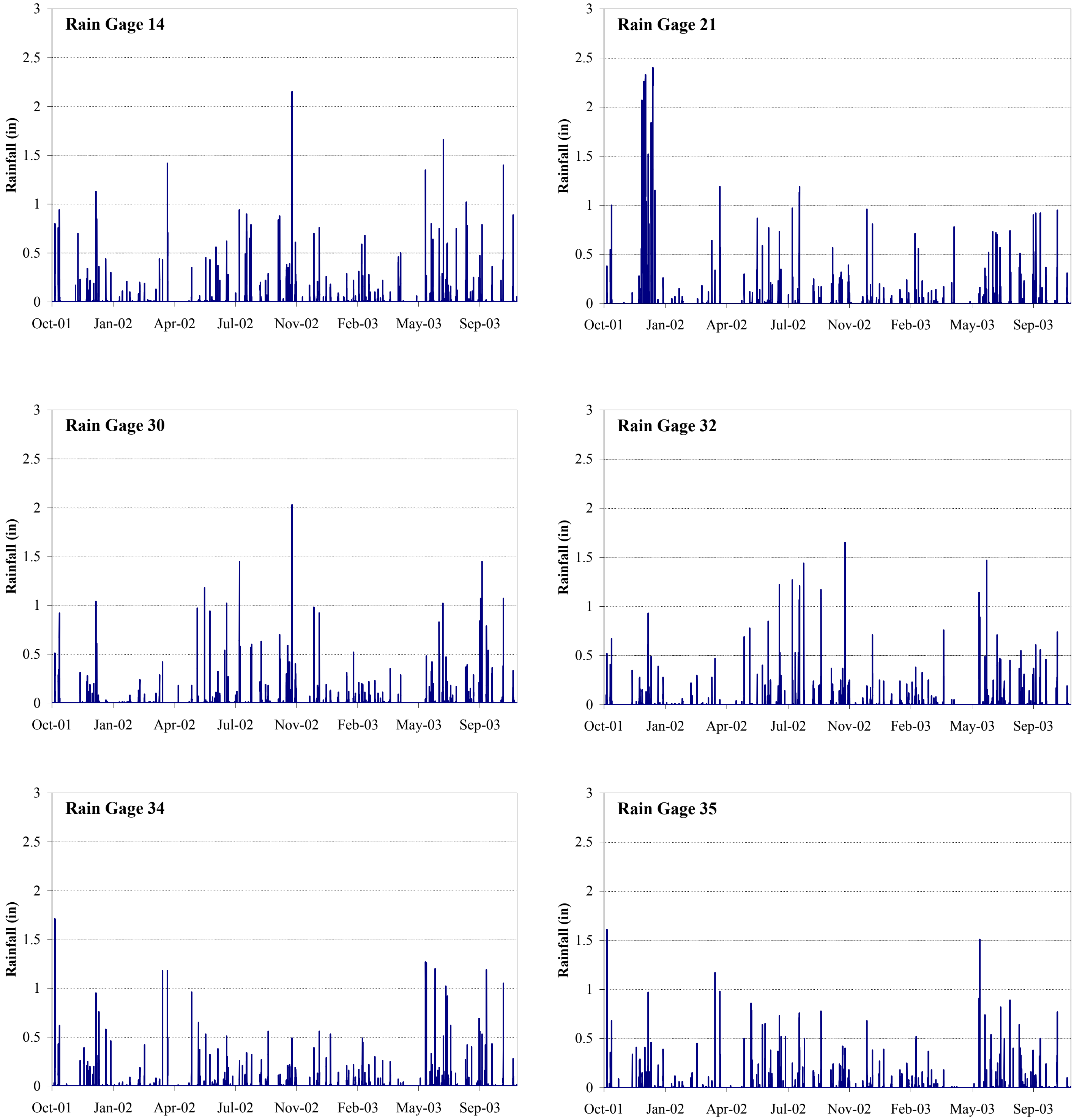


Figure 10.2.1 Precipitation Data for 2001 through 2003

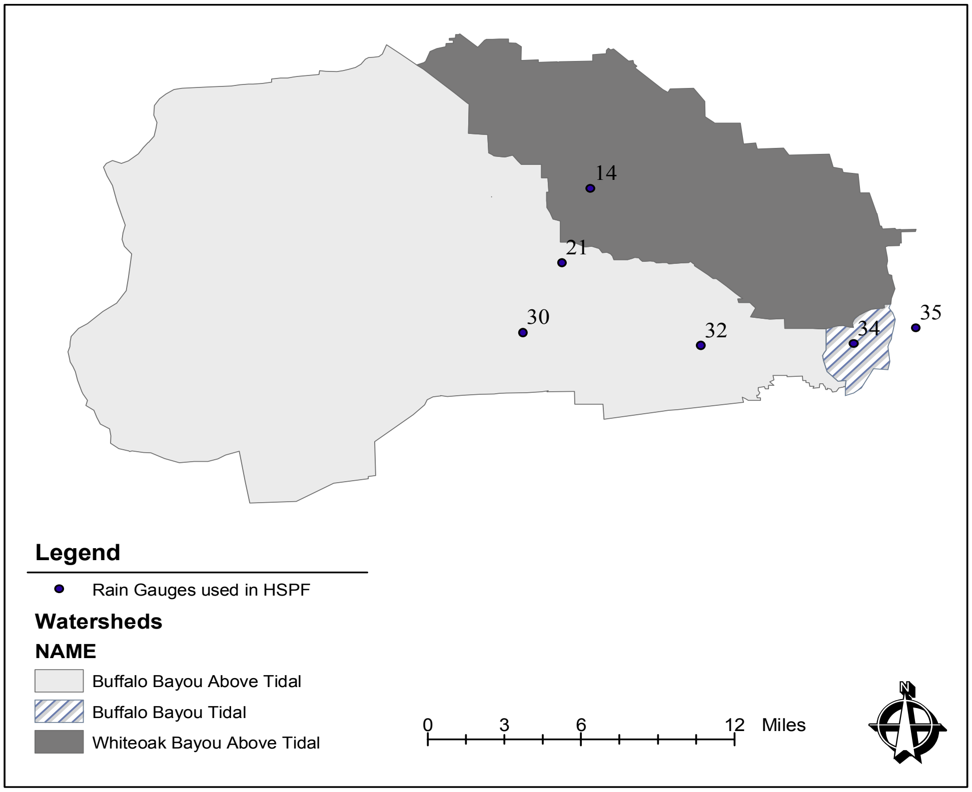


Figure 10.2.2 Location of Rain Gauges in Buffalo and Whiteoak Bayou Watersheds

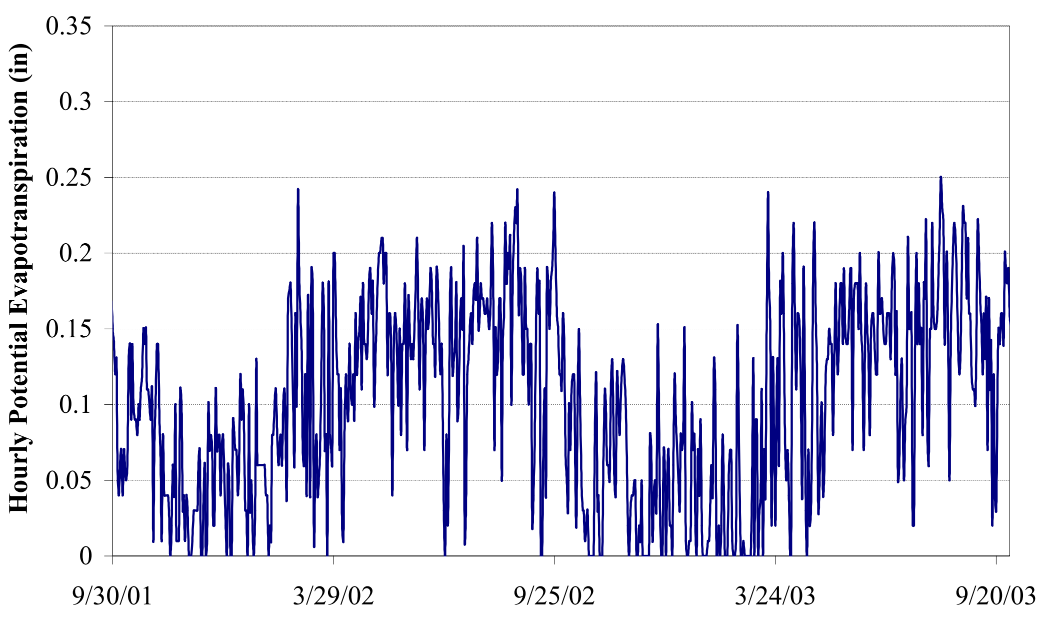


Figure 10.2.3 Potential Evapotranspiration Data for Validation

evapotranspiration (PEVT) data were downloaded from a website maintained by Texas A&M (http://texaset.tamu.edu/pet.php). No data were available for Houston, therefore the sites closest to Houston were used instead; these sites include Ft. Bend, Victoria and Jackson. The data sets for all three sites were incomplete, but Victoria had the most complete record and therefore it was chosen to supply the primary PEVT data set. Data gaps in the Victoria data were filled first using the Jackson data (as it had a higher correlation coefficient to the Victoria data than Ft. Bend). If data were not available from the Jackson data, the Ft. Bend data were utilized. There were still gaps in the data after supplementing the Victoria data with data from Ft. Bend and Jackson. These gaps were filled using one of two methods: (1) the average of the PEVT data surrounding the gap and (2) assuming a constant value equal to the first data point prior to the data gap (this was used for large data gaps). The final PEVT data set is presented in Figure 10.2.3. As can be seen in Figure 10.2.3, the PEVT varies during the year, with the maximum PEVT occurring during the summer.

In addition to the PEVT, evaporation data are also required by HSPF. Hourly evaporation data are not available for the Houston area. Instead, monthly data can be obtained from the Texas Water Development Board (http://hyper20.twdb.state.tx.us/Evaporation/evap.html). To obtain 2001 and 2002 data, the average of the monthly evaporation data for quadrangles 812 and 813 were taken and converted to hourly evaporation. The data on the website are current through 2002, so 2003 was assumed to be the average of 2001 and 2002 data. Figure 10.2.4 presents the final evaporation data. Since data were available only on monthly basis, the evaporation data were input into HSPF using a step-wise graph as shown in Figure 10.2.4.

The flows coming from the Barker and Addicks Reservoirs were another important input into the model (as will be described further in Section 10.3.1.6). The flow data were obtained

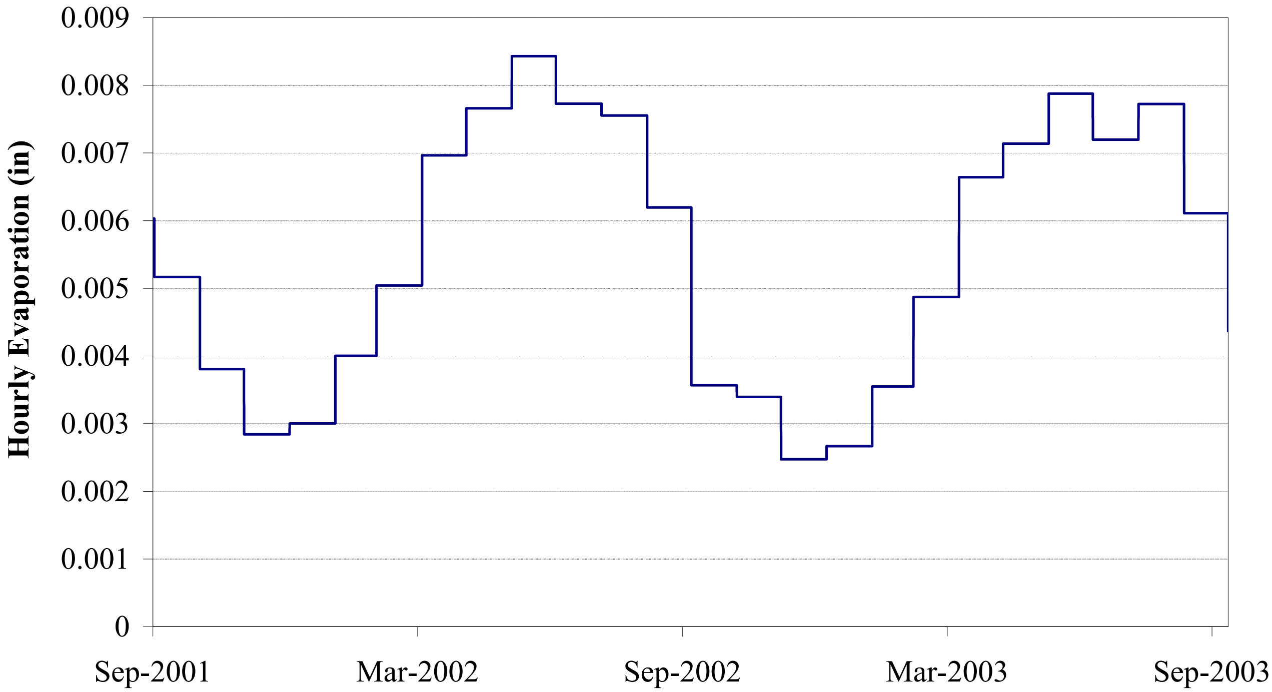


Figure 10.2.4 Evaporation Data for 2001 to 2003

from the U.S. Army Corps of Engineers Field Office in Galveston, Texas. The data are only available on a 6-hour basis, so a constant flow was assumed until a new flow data point was available. The flows from the Addicks and Barker Reservoirs are shown in Figure 10.2.5.

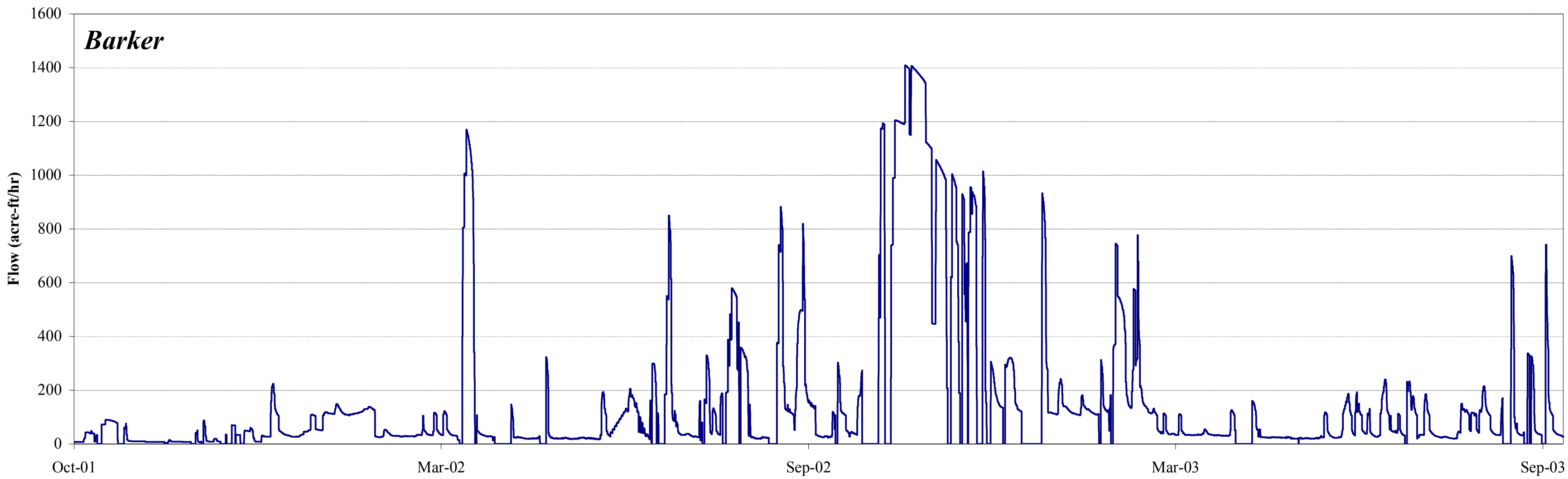
10.2.2 MODEL ASSESSMENT DATA

Hourly data were requested from the USGS for all flow gages in Buffalo and Whiteoak Bayous. Flow data for both bayous from October 1, 2001 through September 30, 2003 are presented in Figures 10.2.6 and 10.2.7.

In addition to flow data, bacteria data are required to validate the model. During the latter portion of the calibration period (around June 2001), the TCEQ began collecting EC data in addition to FC data. Around December 2001, EC data were being collected exclusively. Therefore, model validation was conducted using EC data as shown in Figure 10.2.8.

10.3 BUFFALO BAYOU MODEL EXPANSION

The Buffalo Bayou HSPF model was modified during this work order to include both Addicks and Barker Reservoir watersheds in the modeling domain. This process involved obtaining subwatersheds for the model, revising the hydrology and hydraulics (H&H) for the downstream portion of the model and developing H&H data for the upper watersheds, developing reservoir operation procedures and adjusting the water quality parameters within the model for EC. Once the model was updated, it was calibrated and verified. The following sections describe the model expansion in more detail.



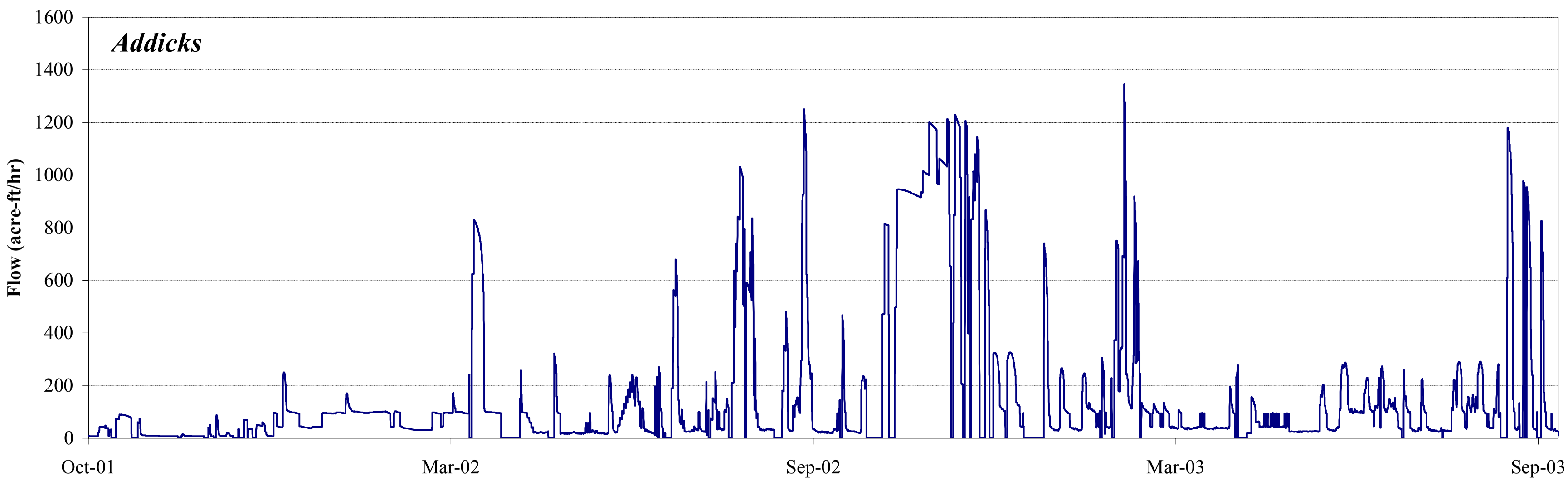


Figure 10.2.5 Barker and Addicks Reservoir Flows

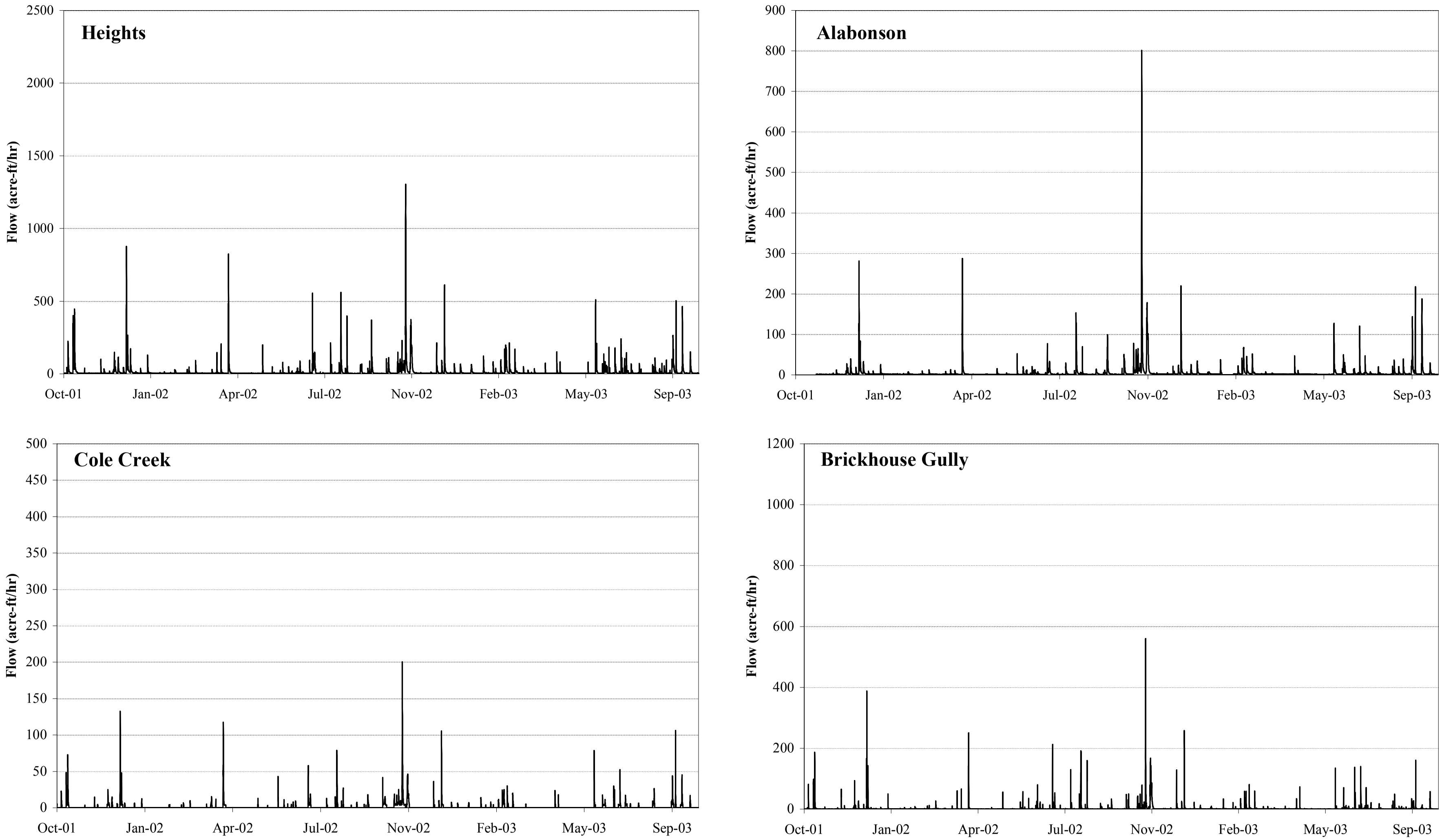


Figure 10.2.6 Whiteoak Bayou Flows for 2001-2003

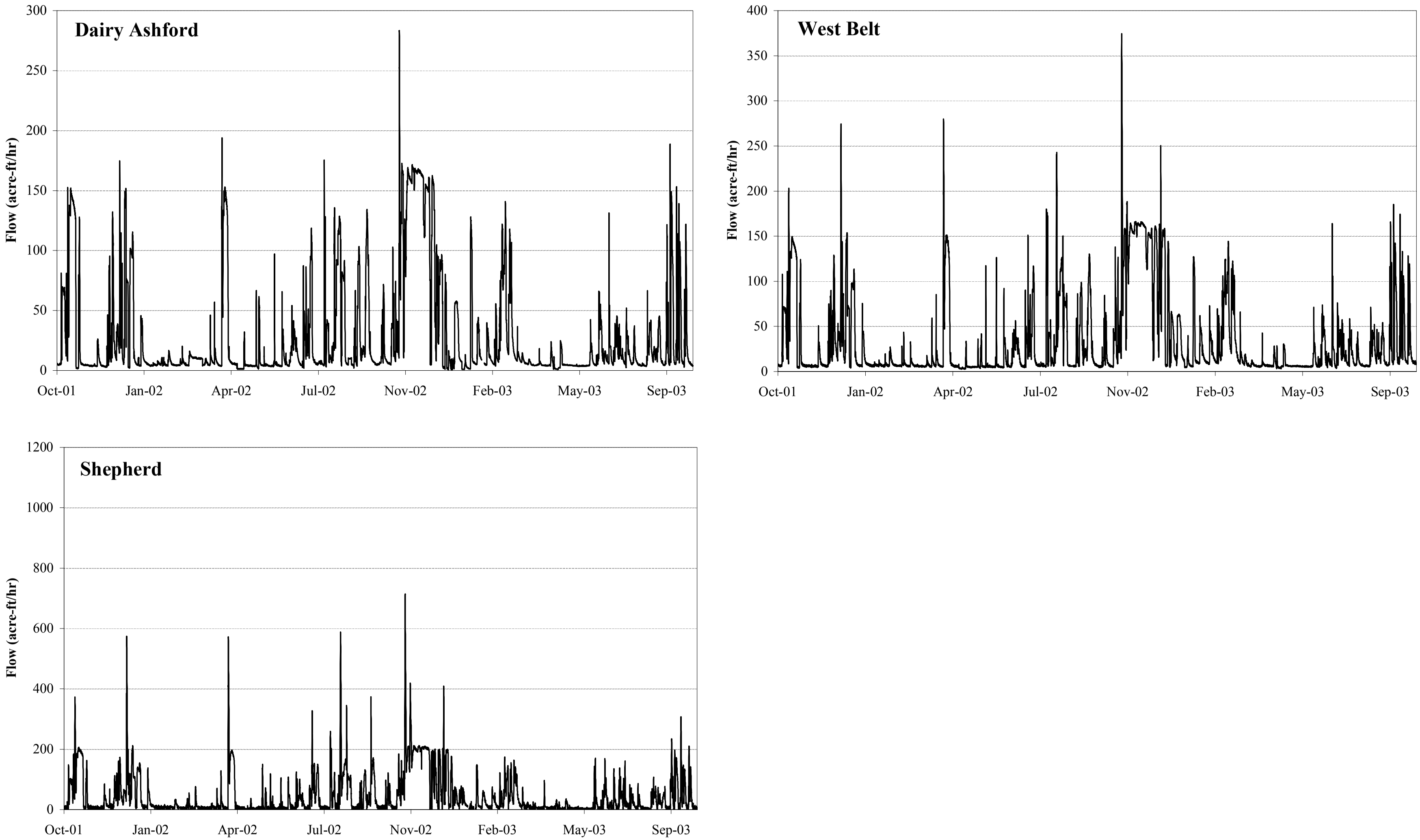


Figure 10.2.7 Buffalo Bayou Flows for 2001-2003

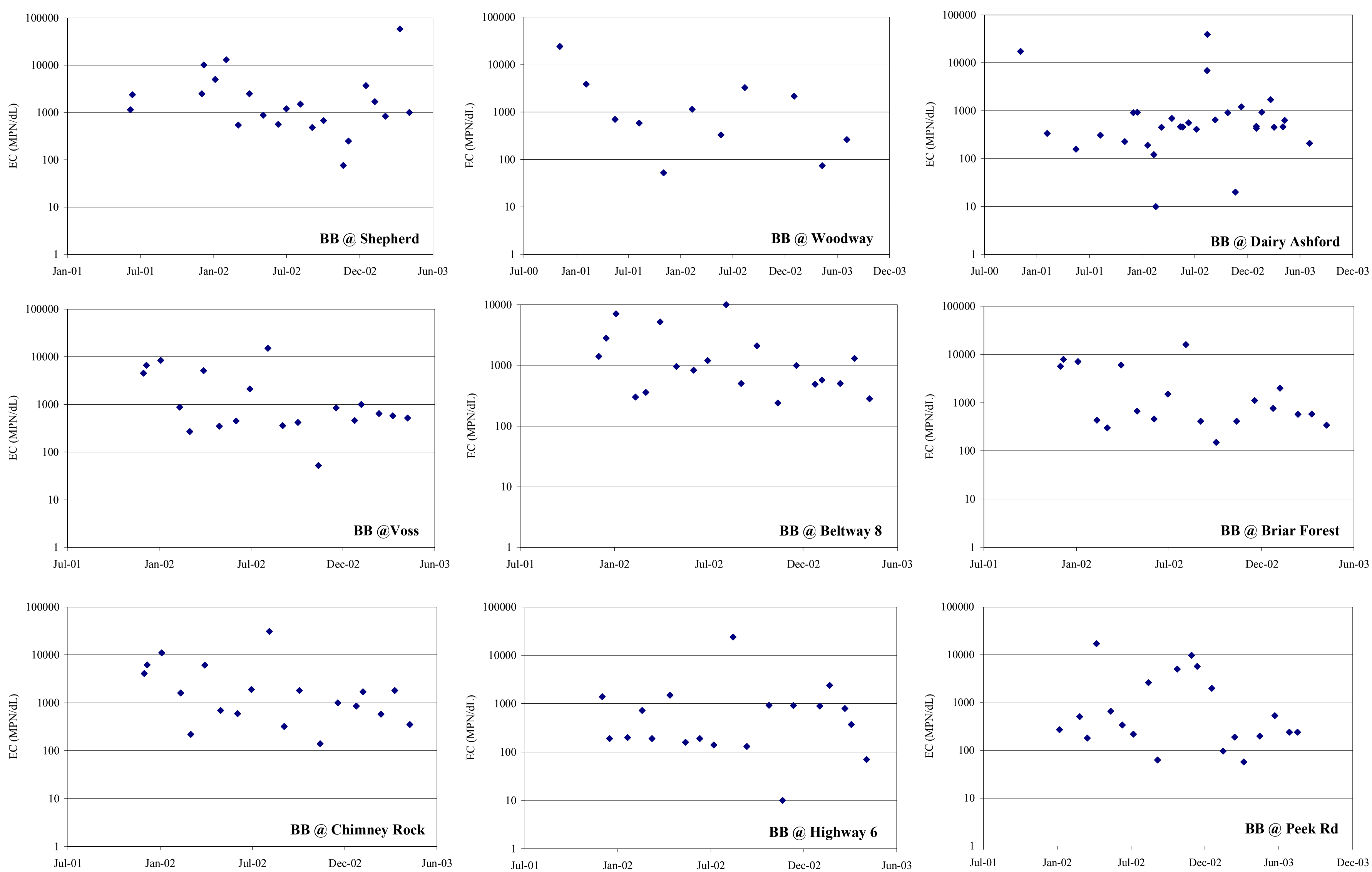


Figure 10.2.8 E. coli data for 2001 to 2003 used for Calibration/Validation

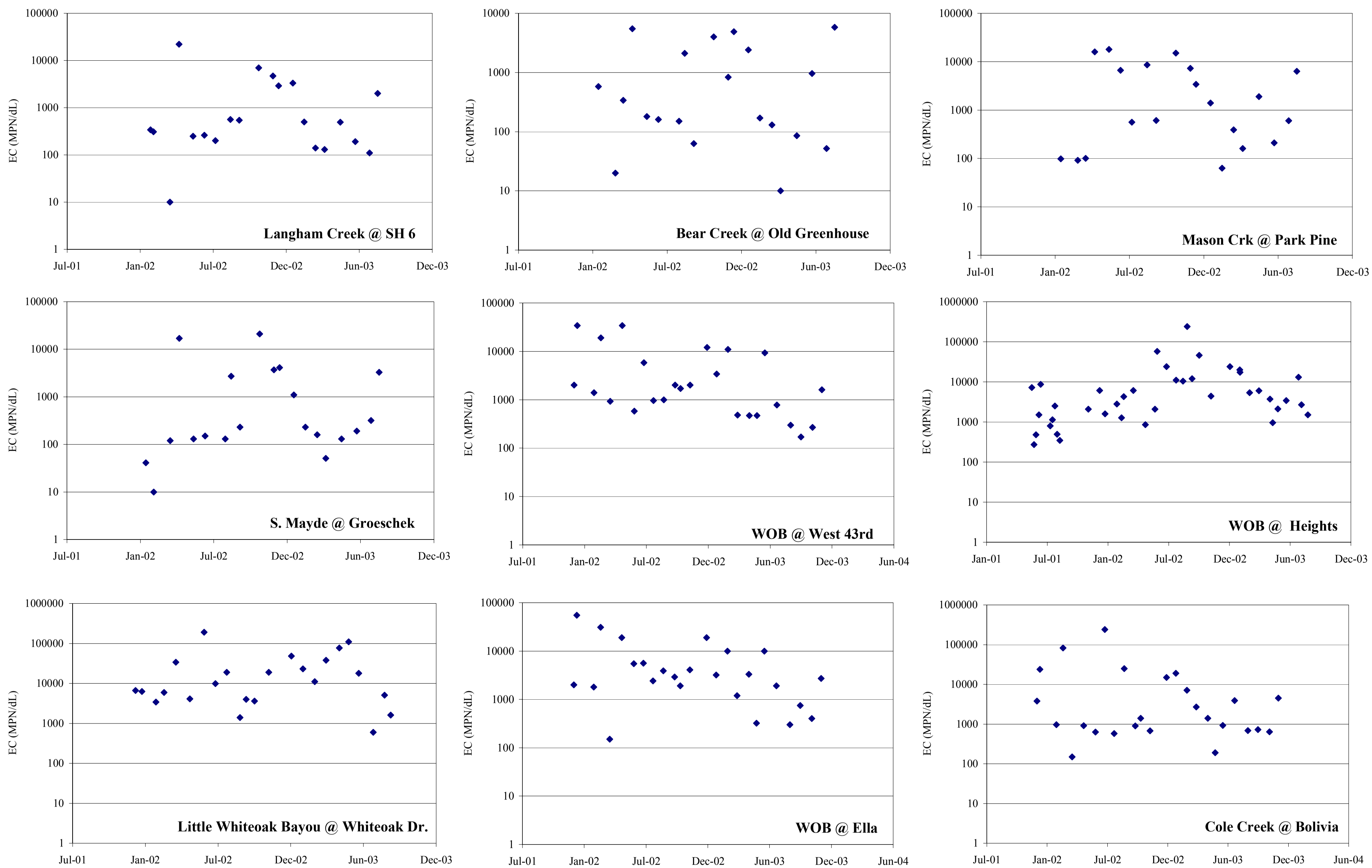


Figure 10.2.8 Observed EC data from 2001 to 2003

10.3.1 DATA COLLECTION - SUBWATERSHEDS AND HYDROLOGY

The project team contacted Harris County Flood Control District (HCFCD) to obtain available data and models produced by the Tropical Storm Allison Recovery Project (TSARP) for the area upstream of the Addicks and Barker dams. The data provided included the new subwatershed boundaries, stream system, and digital elevation model (DEM) in Geographical Information System (GIS) format. The collected GIS data were examined and found to be quite different from the pre-TSARP data, especially the subwatershed delineation boundaries. The examination of the provided TSARP data also showed incomplete DEM and stream systems, mostly on the south and west subwatesheds of Barker reservoir. This data gap resulted because the area in question was outside of Harris County boundary.

In addition to TSARP data, all 22 watersheds of HCFCD are undergoing a Master Watershed Planning (WMP) effort using the TSARP data and models. Among the 22 TSARP watersheds, the Addicks and Barker watersheds are being studied by LAN and Cobb, Fendeley, respectively. These two consulting firms were contacted to obtain additional data to fill the gap was provided. The provided data were then merged with the TSARP data to fill the data gap within the study area. Figure 10.3.1 shows the TSARP subwatershed boundaries and the stream systems. Figure 10.3.2 shows the DEM data.

The latest Land Use/Land Cover (LULC) data were obtained from the Houston-Galveston Area Council (H-GAC). The data include nine LULC categories, as listed in Table 10.3.1 and shown in Figure 10.3.3. Impervious percentages associated with the nine LULC categories were assigned similar values as those previously assigned to areas downstream of the dams. Table 10.3.1 lists the assigned impervious percentage values.

Figure 10.3.4 shows the locations of wastewater treatment plants (WWTPs) identified in

Figure 10.3.1
TSARP Subwatershed Delineation and Stream System

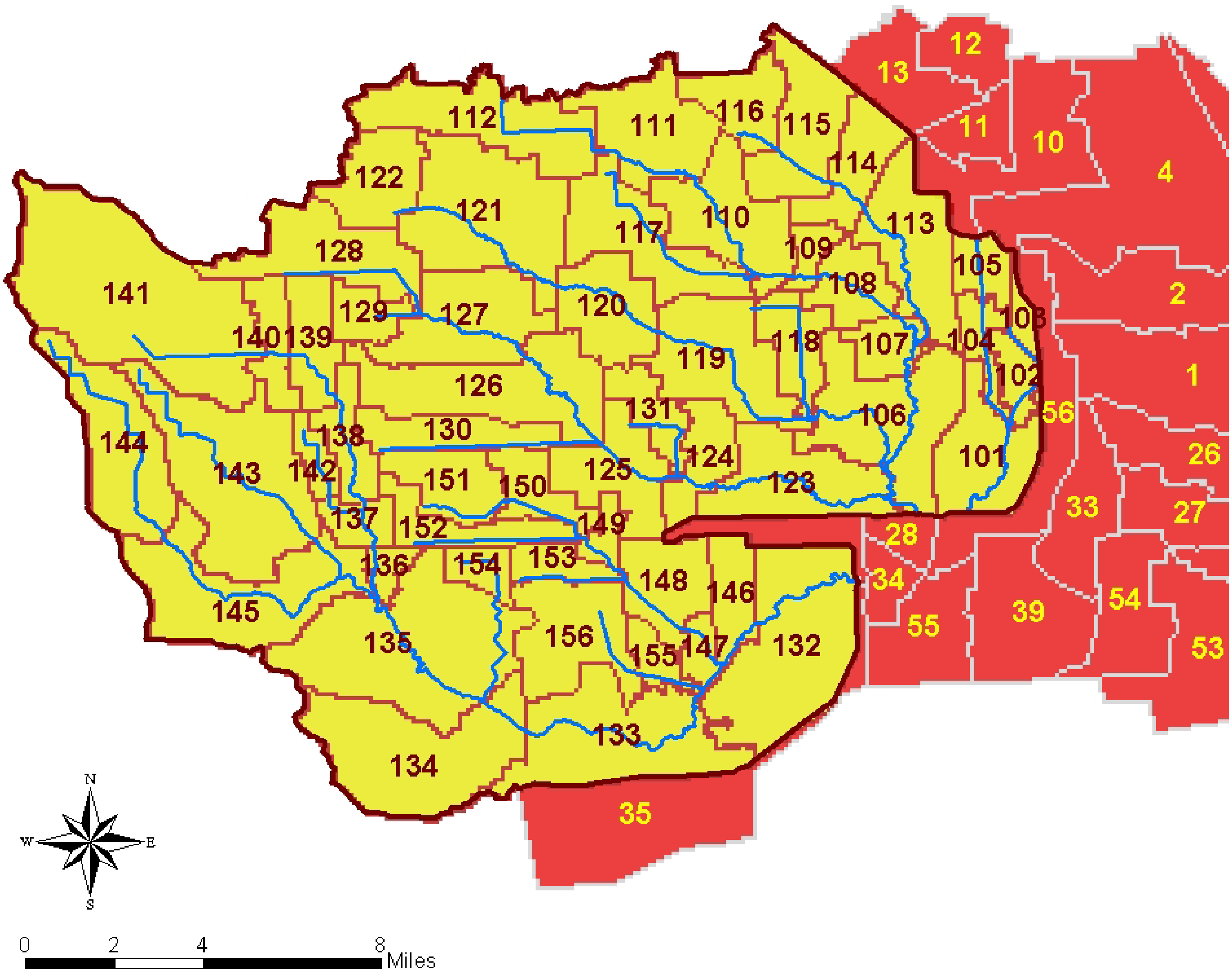


Figure 10.3.2
TSARP DEM Data

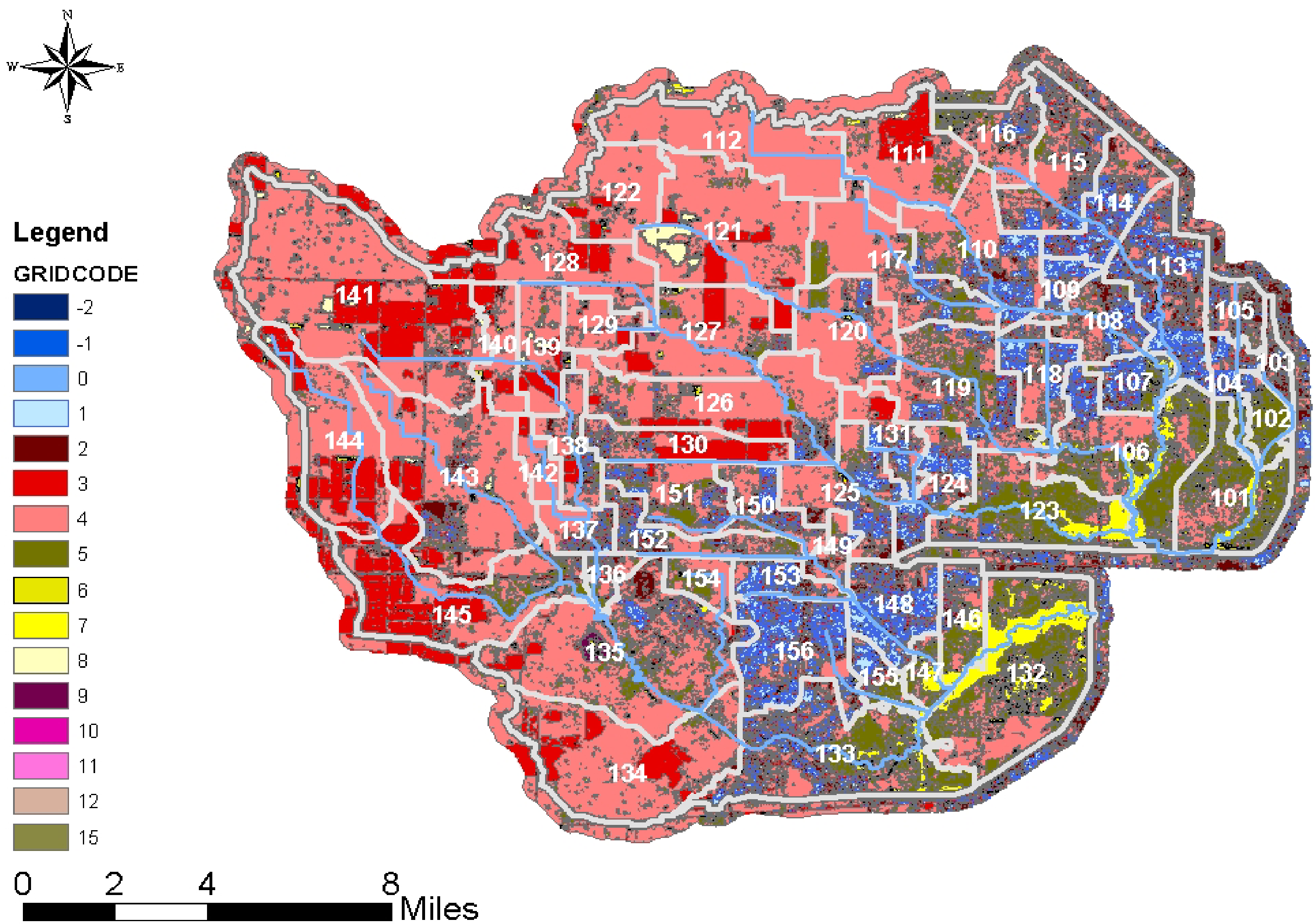


Table 10.3.1
H-GAC LULC Categories and Assigned Impervious Percentages

LULC Categories	% Impervious
Agriculture	0
Bare or Transitional	50
Grassland	0
High Intensity Developed	100
Low Intensity Developed	50
Open Water	100
Wetland	0
Woody Land	0
Woody Wetland	0

Figure 10.3.3
H-GAC Land Use/Land Cover Data

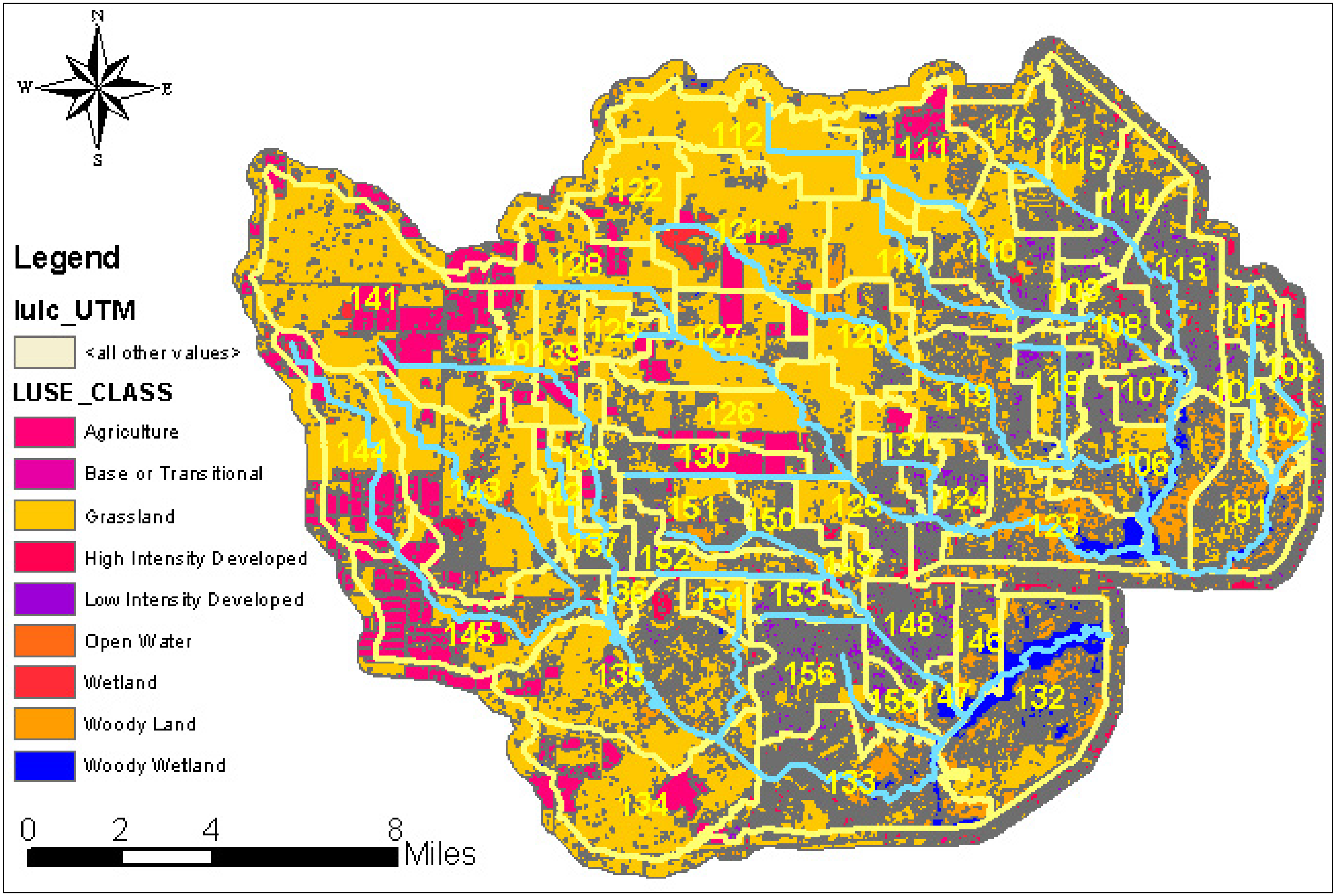
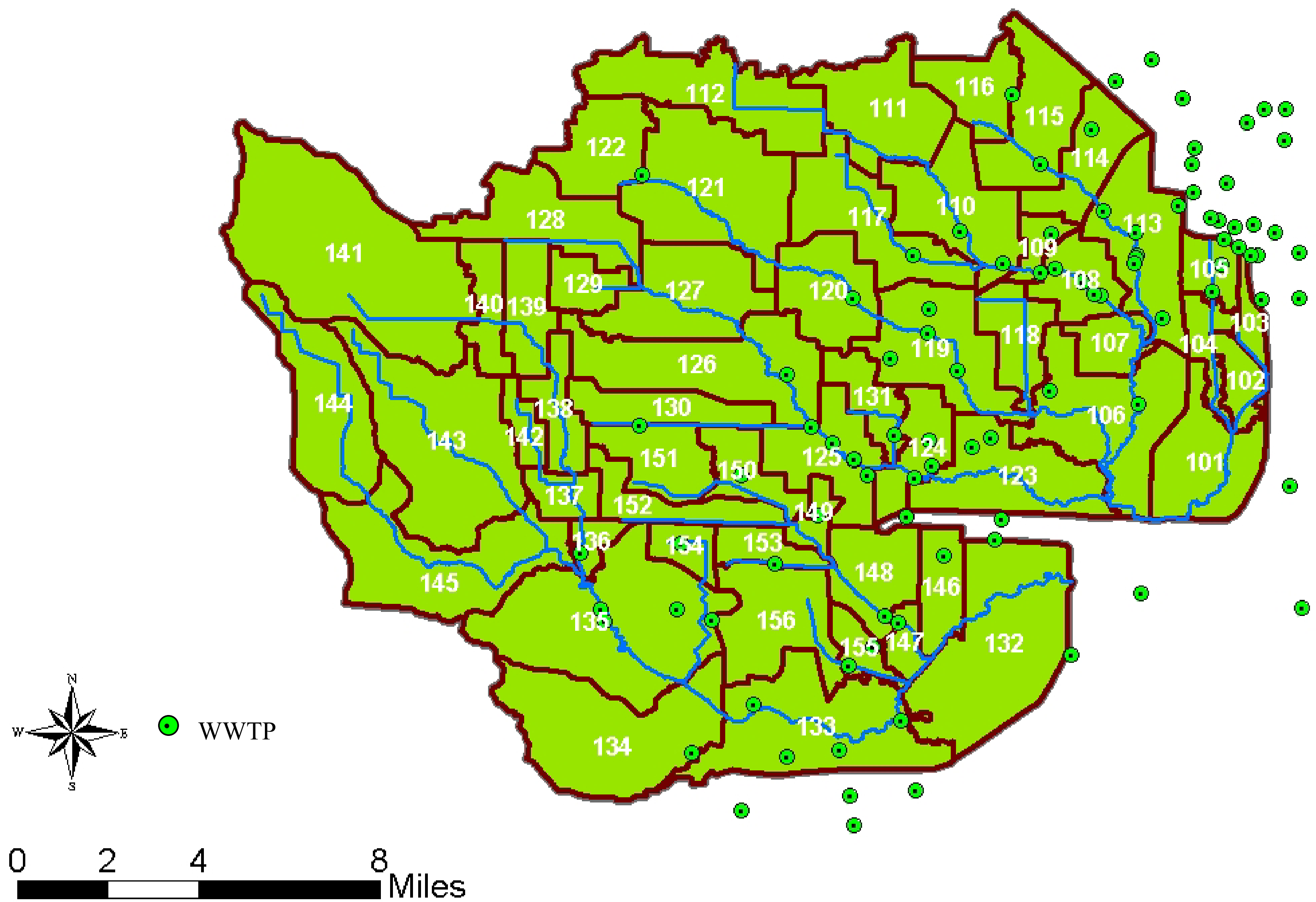


Figure 10.3.4

Locations of Wastewater Treatment Plants within Study Subwatersheds



previous work orders of the project. Wastewater (WW) flow data were retrieved from TCEQ. It was necessary to request WWTP data for a total of three counties, including Harris, Walker and Fort Bend as the TSARP watershed boundaries extend outside of Harris County.

10.3.2 METHODOLOGY FOR MODEL EXPANSION

The collected DEM, stream network, LULC, and WW flow data were intersected with the TSARP subwatershed boundaries to calculate subwatershed specific data needed for expanding the HSPF model. The intersection was conducted using ArcMap 8.3. Attempts were made to conduct data processing using EPA BASINS 3.0 (with ArcView 3.2). However, because the Hydrologic Cataloging Unit in BASINS does not match the TSARP watershed boundary and using user-specified data is still not an option with BASINS 3.0, ArcMap 8.3 was used to process the data.

Tables 10.3.2 and 10.3.3 show the GIS-processed channel lengths and areas of pervious and impervious surfaces, respectively, associated with each subwatershed. The time-varying flows described in Section 10.1 were also incorporated into this model. These data were processed into the WDM and UCI files of the HSPF model developed in WO5 to expand the model to include the areas upstream of the dams. The schematic network for the pervious lands, impervious lands, and reaches of the new subwatersheds was developed following the physical stream system. Hydrologic, hydraulic, and water quality parameters were assigned using values calibrated for the subwatersheds downstream of the dams. These assigned parameters were adjusted during the model calibration and validation process.

Table 10.3.2
Channel Lengths for Areas Upstream of Addicks and Barker Dams

ID	Stream Name	Length (mi)	ID	Stream Name	Length (mi)	ID	Stream Name	Length (mi)
101	Turkey Creek	3.152	120	Bear Creek	3.069	139	Upper Buffalo Bayou	1.634
102	Turkey Creek	1.143	121	Bear Creek	4.114	140	Upper Buffalo Bayou	0.577
103	Turkey Creek	1.306	122	Bear Creek	0.529	141	Upper Buffalo Bayou	3.103
104	Turkey Creek	3.060	123	South Mayde Creek	5.984	142	Upper Buffalo Bayou	2.911
105	Turkey Creek	1.458	124	South Mayde Creek	1.075	143	Upper Buffalo Bayou	7.979
106	Bear Creek	4.720	125	South Mayde Creek	2.322	144	Upper Buffalo Bayou	6.268
107	Langham Creek	3.720	126	South Mayde Creek	3.303	145	Upper Buffalo Bayou	6.777
108	Langham Creek	3.468	127	South Mayde Creek	3.163	146	Upper Buffalo Bayou	1.262
109	Langham Creek	0.597	128	South Mayde Creek	3.639	147	Upper Buffalo Bayou	0.736
110	Langham Creek	3.725	129	South Mayde Creek	1.043	148	Mason Creek	3.146
111	Langham Creek	2.624	130	South Mayde Creek	4.913	149	Mason Creek	1.574
112	Langham Creek	3.480	131	South Mayde Creek	2.321	150	Mason Creek	2.021
113	Horsepen Creek	4.308	132	Upper Buffalo Bayou	3.669	151	Mason Creek	2.031
114	Horsepen Creek	0.972	133	Upper Buffalo Bayou	5.868	152	Mason Creek	3.692
115	Horsepen Creek	1.447	134	Upper Buffalo Bayou	1.153	153	Mason Creek	2.436
116	Horsepen Creek	0.970	135	Upper Buffalo Bayou	4.581	154	Upper Buffalo Bayou	4.567
117	Dinner Creek	4.925	136	Upper Buffalo Bayou	1.384	155	Upper Buffalo Bayou	1.493
118	Bear Creek	3.750	137	Upper Buffalo Bayou	0.985	156	Upper Buffalo Bayou	1.770
119	Bear Creek	4.823	138	Upper Buffalo Bayou	3.119			

Table 10.3.3
Pervious and Impervious Areas for Areas Upstream of Addicks and Barker Dams

ID	Imp Acres	Perv Acres	% Imp	ID	Imp Acres	Perv Acres	% Imp
101	79.5	3,411.2	2.28%	129	81.7	1,105.8	6.88%
102	84.0	922.7	8.34%	130	164.7	1,878.8	8.06%
103	347.8	258.2	57.39%	131	294.6	1,168.2	20.14%
104	373.9	718.8	34.22%	132	129.9	6,947.4	1.83%
105	459.5	663.0	40.94%	133	1,566.1	4,694.8	25.01%
106	360.1	5,044.7	6.66%	134	236.9	6,194.5	3.68%
107	314.7	1,001.8	23.91%	135	1,053.3	7,383.2	12.48%
108	579.8	1,287.8	31.04%	136	154.1	500.5	23.55%
109	291.0	467.6	38.36%	137	158.0	879.3	15.23%
110	804.6	3,065.1	20.79%	138	219.8	1,371.3	13.81%
111	8.0	3,639.8	0.22%	139	126.7	1,789.0	6.61%
112	3.2	4,448.0	0.07%	140	96.4	1,414.6	6.38%
113	1,595.3	2,273.3	41.24%	141	394.5	10,242.7	3.71%
114	790.9	1,494.8	34.60%	142	7.1	802.0	0.88%
115	1,038.5	2,398.2	30.22%	143	718.4	6,672.7	9.72%
116	312.5	1,708.4	15.46%	144	60.9	4,334.4	1.39%
117	343.1	3,627.3	8.64%	145	406.3	5,628.9	6.73%
118	513.1	1,425.8	26.46%	146	275.7	1,340.0	17.06%
119	647.2	3,631.3	15.13%	147	17.9	710.7	2.46%
120	311.9	2,644.7	10.55%	148	1,074.2	1,435.7	42.80%
121	43.4	6,169.2	0.70%	149	196.1	534.3	26.85%
122	41.2	2,483.2	1.63%	150	292.7	1,327.8	18.06%
123	251.9	3,814.3	6.19%	151	375.2	1,825.9	17.04%
124	635.3	1,221.2	34.22%	152	521.1	1,361.2	27.68%
125	786.3	2,227.5	26.09%	153	445.4	631.9	41.35%
126	375.5	4,947.6	7.05%	154	92.3	879.4	9.49%
127	130.0	3,889.0	3.23%	155	252.3	668.1	27.41%
128	124.4	3,549.7	3.39%	156	1,616.5	2,083.9	43.68%

10.3.3 DEVELOPMENT OF FTABLES FROM TSARP HEC-RAS MODELS

The HSPF model uses the FTABLES to conduct water balance calculations within each channel reach or reservoir segment (RCHRES). The FTABLE of a RCHRES is a rating relationship among the water depth, water surface area, volume, and outflow discharge of the reach. These relationships can be either developed using channel geometry and roughness information or treated as calibration parameters. However, due to the large number of values involved in the FTABLES, trying to adjust all these values during the model calibration process can be a significant task. Thus, a better approach would be to develop FTABLES out of available channel information and then conduct only minor adjustment as needed during the model calibration process.

In addition, when existing hydraulic models such as HEC-RAS were available, the models were fused to develop the FTABLES. This not only will allow efficient development of the FTABLES but will also ensure consistency between the developed HSPF model and the HEC-RAS models. By executing the HEC-RAS model using multiple flow values, HEC-RAS will calculate a set of water depth, top width, and volume associated with each flow that can be easily converted to an FTABLE. One key task in doing this is to ensure the correct reference between the RCHRES locations in HSPF and the locations of cross sections in HEC-RAS.

For the expansion of the BB HSPF model to include the Addicks and Barker reservoirs, the TSARP HEC-RAS models for these two areas were requested. However, the official release of these models by HCFCD cannot be done until the watersheds have completed the FEMA review process and approvals from FEMA and HCFCD have been issued. Due to the schedule limitation of this bacteria TMDL project, HCFCD released a set of TSARP HEC-RAS models to the project team for use in the expansion of the HSPF model. It must be noted that this version of the TSARP HEC-RAS models may not be the final FEMA-approved version and differences might exist between the two versions. However, given that the most critical data needed for FTABLES development is channel geometry, that is based on actual field survey; these data are less likely to change in future versions of the models.

One significant advantage of obtaining the TSARP HEC-RAS models is that the models have been geo-referenced using GeoRAS. This allows easy linkage between HSPF RCHRES and the HEC-RAS cross sections. Figure 10.3.5 shows an example HEC-RAS geometry window where geo-referenced channel cross sections are displayed.

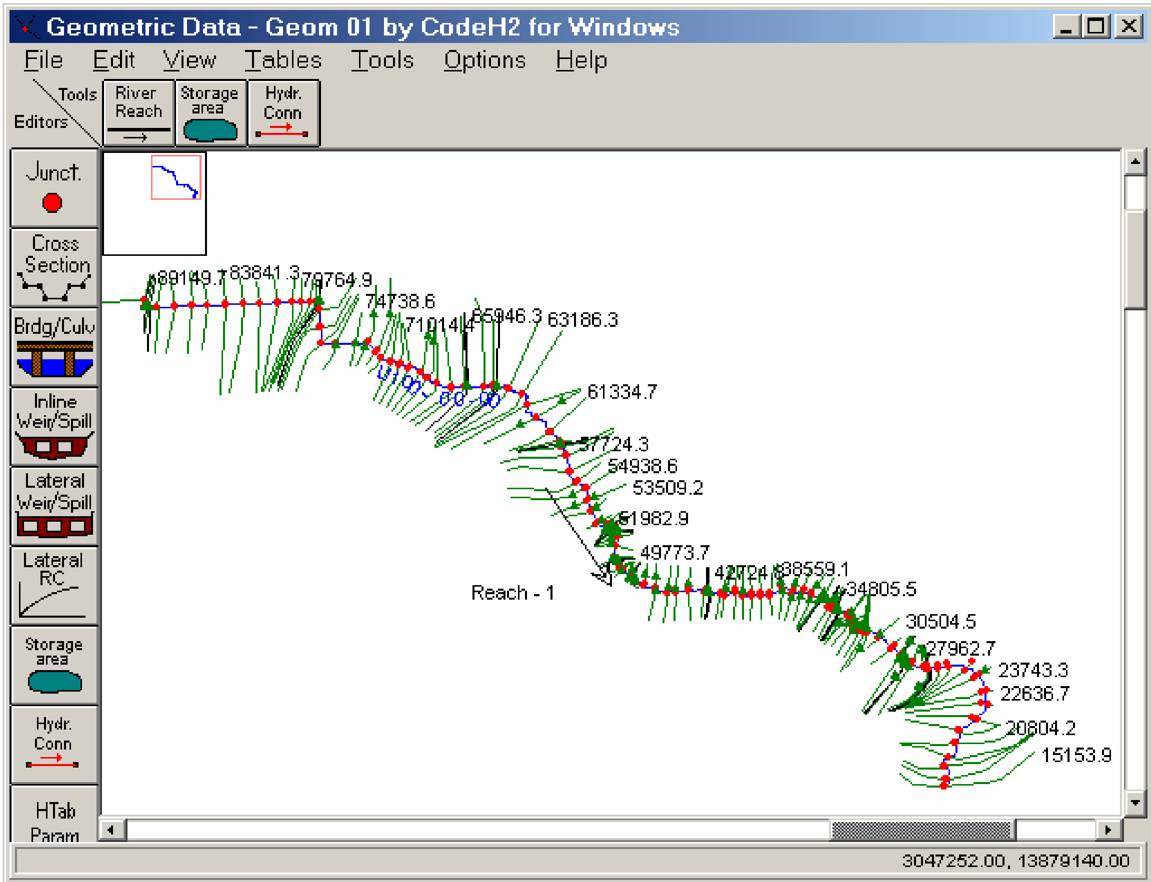
Thus, output from the TSARP HEC-RAS models was processed to create the FTABLES needed for the HSPF models. For reaches not covered by the HEC-RAS models, values derived from similar or nearby TSARP reaches were used to set up the FTABLES and then adjusted if necessary during the calibration process.

10.3.4 ADDICKS AND BARKER RESERVOIR GATE SIMULATION

Both the Addicks and Barker reservoirs are operated by the U.S. Army Corps of Engineers (USACE) for flood control. The operation of these reservoirs is based on the observed flow at the Piney Point gage maintained by the U.S. Geological Survey (USGS). As a general rule, the combined release of the two reservoirs cannot exceed the difference between the observed flow at the Piney Point gage and 2,000 cubic feet per second (cfs). When the flow at Piney Point exceeds or is anticipated to exceed 2,000 cfs, the gates of the two reservoirs are typically closed and no discharge occurs until the Piney Point flow drops below 2,000 cfs again and the threat of additional rain has passed.

The FTABLES for the two subwatersheds (123 and 132) immediately upstream of the

Figure 10.3.5
Example TSARP HEC-RAS Model Showing Geo-Referenced Cross Sections



reservoir gates were set up based on the TSARP HEC-RAS models and the information provided by USACE. The information includes the height of the spillway crest, the height of the embankment, and the length of weir. A typical rectangular weir formula was used to derive the stage-discharge relationships for the two reservoirs.

Given that HSPF is designed for the simulation of well mixed, free-flowing reservoirs, it is difficult to simulate the operation of reservoir gates in HSPF. However, through the use of the Special Actions function in HSPF, the opening and closing of the reservoir gates can be simulated. This was achieved by setting up two dummy subwatersheds (991 and 992 in Table 10.3.4) where the observed time series of reservoir releases were entered into the model. The FTABLES for the two subwatersheds immediately upstream of the reservoir gates (123 and 132 in Table 10.3.4) were then modified to include an additional column with outflow being zero for simulating gate closing conditions.

Based on the value of the observed release at a given time step, the Special Actions listed in Table 10.3.4 selects one of the two columns of the FTABLES for reservoir release calculations. If the observed flow is zero in a given time step, the FTABLE column that produces zero outflow will be selected and therefore the gates are totally closed. If the observed flow is greater than zero, then the FTABLE column that produces a combined flow of 2,000 cfs from the two reservoirs will be selected. However, due to lack of data and the limitations of the HSPF model, the developed BB model still cannot simulate the conditions with the reservoir gates partially closed.

10.3.5 HYDROLOGIC CALIBRATION/VALIDATION

After the HSPF model was modified to include the areas upstream of the Addicks and

Table 10.3.4
Special Actions in HSPF to Simulate Closing and Opening of Reservoir Gates

```
SPEC-ACTIONS
***                        <addrss>
***                           or                         lc ls ac as agfn
***kwrd> <uqnm> <oper> <#> <vari><1><2><3><t><multfact> <>< > <>< > <  >
  UVQUAN addick PERLND 991 IFWLI
  UVQUAN barker PERLND 992 IFWLI
***                                       <addrss>              <uvqn>
***           dc ds                 d t      or                   or   tc ts num
***oper><f>< l><>< ><yr><m><d><h><m><><>  <vari><1><2><3><a>< value  > <> < >< >
IF (addick = 0 AND barker = 0) THEN
  RCHRES123                           2  ODFVFG  1        =         5
  RCHRES132                           2  ODFVFG  1        =         5
ELSE IF (addick > 0 AND barker = 0) THEN
  RCHRES123                           2  ODFVFG  1        =         4
  RCHRES132                           2  ODFVFG  1        =         5
ELSE IF (addick = 0 AND barker > 0) THEN
  RCHRES123                           2  ODFVFG  1        =         5
  RCHRES132                           2  ODFVFG  1        =         4
ELSE
  RCHRES123                           2  ODFVFG  1        =         4
  RCHRES132                           2  ODFVFG  1        =         4
END IF
END SPEC-ACTIONS
```

Barker reservoirs, hydrologic calibration and validation of the model was undertaken. Hydrologic calibration was completed using data between January 1, 2001 (when the earliest EC data are available) and September 30, 2002. Validation/verification of the model was conducted using data between October 1, 2002 and September 30, 2003.

The model calibration and validation was focused on achieving a reasonable water balance for the following three primary areas: overall, low, and high flows or volumes. The stations used for model calibration and validation were the Addicks and Barker Reservoirs, Dairy Ashford, West Belt, and Shepherd (high flows only).

The overall flow calibration and validation was conducted by examining the total volume over the corresponding simulation period. This was conducted by comparing the sums of the observed and modeled flows. To ensure consistency, model outputs within the gaps of the observed data were not included in the sums. The goal of this overall total volume comparison was for the modeled sum to be within 25% of the observed sum. Previous modeling efforts in Work Orders 2 and 5 achieved between 4% to 21% accuracy.

The low-flow model calibration and validation involved several criteria. The first criterion involved the comparison of the observed and modeled 10th-, 20th-, and 30th-percentile low flows. The goal was to obtain the best fit possible. The second criterion was to compare the observed and modeled volumes associated with the summer months (June, July and August). The goal of this second criterion was to obtain the best fit possible. A third criterion for low-flow calibration involved comparing the observed and modeled total volumes of all flows less than the 30th percentile flows. This was conducted by first calculating the sum of all observed flows that fall below the 30th percentile flow. All modeled flows that paired with the observed flows in the sum were than totaled and compared to the observed sum. The goal of this comparison was also to achieve the best fit between the observed and modeled values.

For model calibration and validation of high (storm) flow data, ten storm events were selected within the calibration period and five events were selected within the validation period, as listed in Table 10.3.5. Each selected storm event would begin and end based on either the rainfall (from no rainfall back to no rainfall) or the flow (from pre-storm levels back to similar levels). The total modeled and observed volumes of these selected events were then compared against the goal of having a smaller than 20% difference between the two volumes.

In addition, other graphical comparisons including time series plots were used to demonstrate the fit between the modeled and observed data. The HSPF model parameters were adjusted during the model calibration process to improve the fit between the modeled and observed data. However, the adjustment of these parameters was limited to predetermined and reasonable ranges. Once the differences between the modeled and observed data were within the specified goals for the calibration period, the calibrated model was executed for the validation period without additional adjustment to the parameters.

Table 10.3.6 shows the results of model calibration and validation. The results indicated that all specified goals for model calibration and validation were met except for the storm volume at the Barker and Addicks discharges and at the Dairy Ashford gage. This mismatch was found to be the result of two problems: (1) data gaps in the rainfall and flow time series and (2) the reservoir gate operation. As would be expected, rainfall is an important input to the model that produces flows as output, and any inconsistent gaps in the observed rainfall and flow time series would result in a mismatch between the modeled and observed flows. To address the problem associated with rainfall, more rainfall gages will be added to the simulation in the future.

Table 10.3.5

Selected Storm Events for HSPF Model Calibration and Validation

Storm Events for Calibration:		Peak Rainfall	
Start	End	Time	Inches
03/15/2001 10:00	03/18/2001 18:00	03/14/2001 15:00	0.78
03/27/2001 12:00	3/29/2:001 17:00	03/27/2001 17:00	0.88
05/26/2001 15:00	05/30/2001 06:00	05/26/2001 15:00	1.14
06/08/2001 17:00	06/11/2001 10:00	06/08/2001 23:00	1.27
07/02/2001 14:00	07/03/2001 23:00	07/02/2001 14:00	1.16
08/06/2001 18:00	08/11/2001 03:00	08/06/2001 19:00	1.13
09/22/2001 16:00	09/23/2001 07:00	09/22/2001 6:00	0.78
12/11/2001 12:00	12/15/2001 23:00	12/11/2001 23:00	1.04
05/26/2002 15:00	05/27/2002 12:00	05/26/2002 16:00	0.97
08/03/2002 16:00	08/06/2002 02:00	08/03/2002 17:00	1.45
Storm Events for Validation:		**Peak Rainfall**	
Start	End	Time	Inches
10/28/2002 11:00	11/03/2002 00:00	10/28/2002 19:00	2.03
12/10/2002 09:00	12/17/2002 23:00	12/12/2002 11:00	0.92
06/26/2003 12:00	06/29/2003 18:00	06/26/2003 12:00	0.83
07/02/2003 15:00	07/06/2003 23:00	07/02/2003 15:00	1.02
09/04/2003 13:00	09/10/2003 04:00	09/04/2003 17:00	1.45

Table 10.3.6 Summary of Hydrologic Model Performance for Buffalo Bayou

Calibration (1/1/2001 - 9/30/2002)

Data Source	Location	Total Volume	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Barker	1.97E+05	44.38	0.00	2.50	6.62E+03	3.47E+04
	Addicks	2.21E+05	56.4	0.00	3.20	7.51E+03	5.89E+04
	Dairy Ashford	4.07E+05	104.6	3.76	4.96	2.66E+04	9.94E+04
	West Belt	4.75E+05	118.6	5.31	6.44	4.40E+04	1.25E+05
	Shepherd[4]	7.38E+05	168.8	5.22	8.94	9.63E+04	2.19E+05
Modeled	Barker	1.94E+05	50.5	0.00	2.00	8.37E+03	4.84E+04
	Addicks	2.15E+05	31.4	2.20	3.70	1.05E+04	5.60E+04
	Dairy Ashford	4.70E+05	84.2	4.60	8.10	3.30E+04	1.25E+05
	West Belt	4.93E+05	88.6	4.80	8.60	4.02E+04	1.33E+05
	Shepherd[4]	6.87E+05	134.0	8.20	14.80	8.61E+04	1.96E+05
Error[3]	Barker	-2%	14%	-[5]	-20%	27%	39%
	Addicks	-3%	-44%	-[5]	16%	40%	-5%
	Dairy Ashford	15%	-19%	22%	63%	24%	26%
	West Belt	4%	-25%	-10%	34%	-9%	7%
	Shepherd[4]	-7%	-21%	57%	66%	-11%	-11%

Validation (10/1/2002 - 9/30/2003)

Data Source	Location	Total Volume	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Barker	1.49E+05	62.9	0	2.5	2.12E+04	1.39E+04
	Addicks	1.56E+05	75.9	0	2.9	2.58E+04	1.93E+04
	Dairy Ashford	2.87E+05	120.9	3.8	5.3	4.50E+04	3.14E+04
	West Belt	3.48E+05	141.7	5.8	7.5	6.17E+04	4.07E+04
	Shepherd[4]	4.34E+05	191.0	4.9	11.0	8.62E+04	5.71E+04
Modeled	Barker	1.48E+05	56.3	0	2	2.61E+04	1.74E+04
	Addicks	1.66E+05	67.3	2.0	4.4	2.95E+04	2.12E+04
	Dairy Ashford	3.58E+05	126.1	4.5	10.7	6.42E+04	4.66E+04
	West Belt	3.73E+05	129.0	4.7	11.6	6.78E+04	4.92E+04
	Shepherd[4]	4.53E+05	156.0	8.4	21.2	8.35E+04	6.66E+04
Error[3]	Barker	-1%	-10%	-[5]	-20%	23%	26%
	Addicks	6%	-11%	-[5]	52%	14%	10%
	Dairy Ashford	25%	4%	17%	101%	43%	48%
	West Belt	7%	-9%	-18%	54%	10%	21%
	Shepherd[4]	4%	-18%	70%	92%	-3%	17%

Notes:

[1] Volumes are in acre-ft/hr

[2] Storm volumes were calculated using dates presented in Table 10.3.5

[3] Error percentage calcualted as (Model Value - USGS Value) / USGS Value, 0% indicates perfect match

[4] Flow statistics compiled for Shepherd gage only when observed flow available.

[5] Error can not be computed due to 0 value.

Errors caused by reservoir gate operation have been examined in detail and there are some potential issues with the reservoir operation that need to be noted. In general, the HSPF model does a relatively good job of matching the observed flows from the reservoir, but in highly complex cases, the model cannot adequately simulate the reservoir releases. This is illustrated in Figure 10.3.6. In Figures 10.3.6 (a) and (b), Barker and Addicks Reservoirs exhibit a reasonable match between observed and modeled data. In Figures 10.3.6 © and (d), however, the intricacies of the observed data are not present in the model data. These inadequacies are not necessarily failings of the model, but are pointed out to explain why the high flow and storm volumes from the reservoir do not match observed data as well as other metrics used for model evaluation.

Figure 10.3.7 shows the observed rainfall, flow, and the modeled flow time series at Barker, Addicks, Dairy Ashford, West Belt, and Shepherd. These plots show good general match between the observed and modeled data. The very high modeled flow discharges from the reservoirs do not always match what is seen in the observed data. This confirms the findings described in the above paragraphs regarding the reservoirs.

Other plots were prepared for the assessment of the hydrologic calibration. Flow duration curves were developed for each gage and are presented in Figure 10.3.8. These plots demonstrate that low flows are underestimated at Dairy Ashford, West Belt and Barker Reservoir. The mid-range flows are generally overestimated by the model. Plots of modeled data versus observed data are presented for individual stations in Figure 10.3.9. The r^2 values reported in these one-to-one plots range between 0.406 and 0.6095, indicating a relatively good fit between model and observed data.

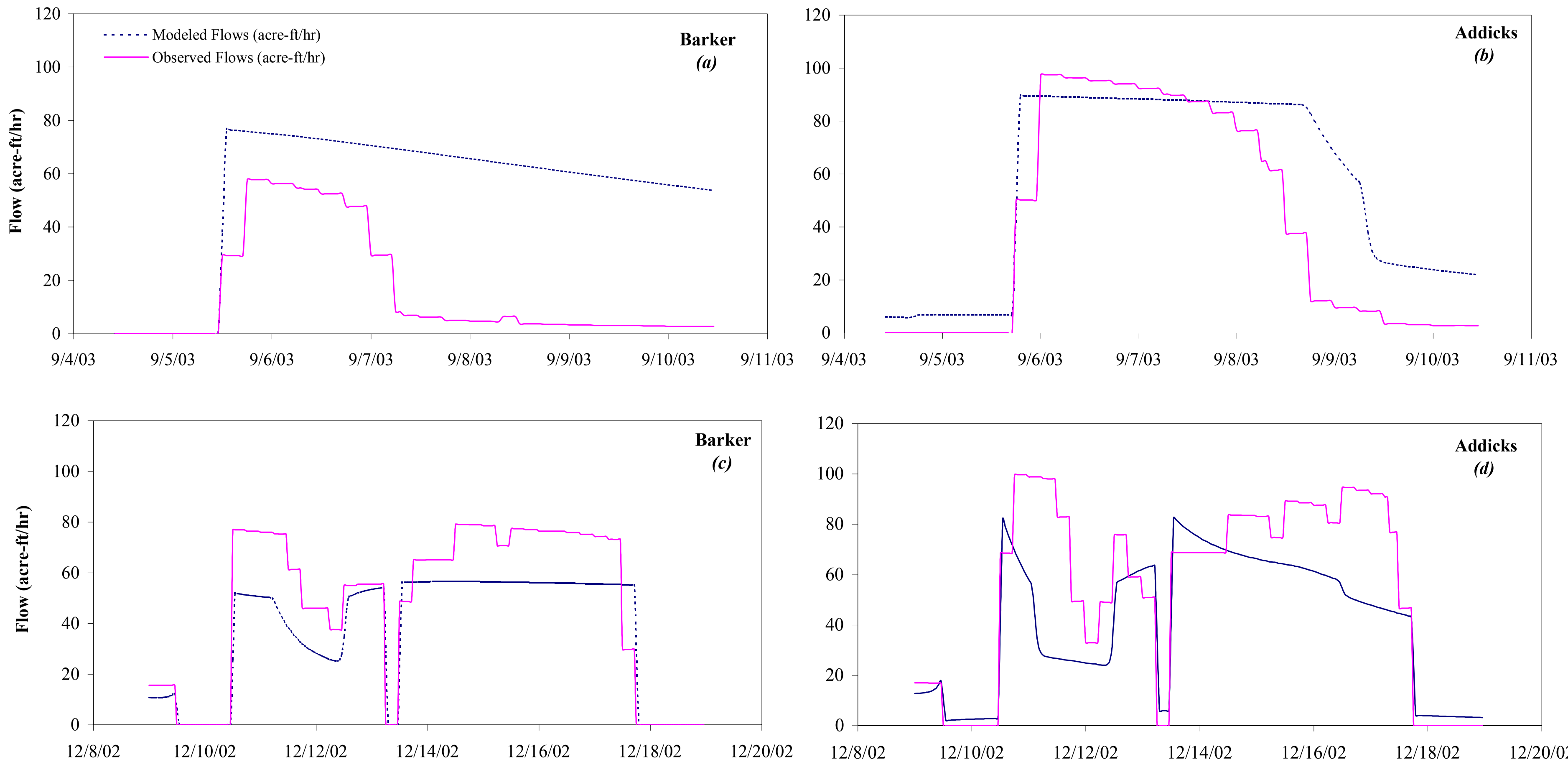
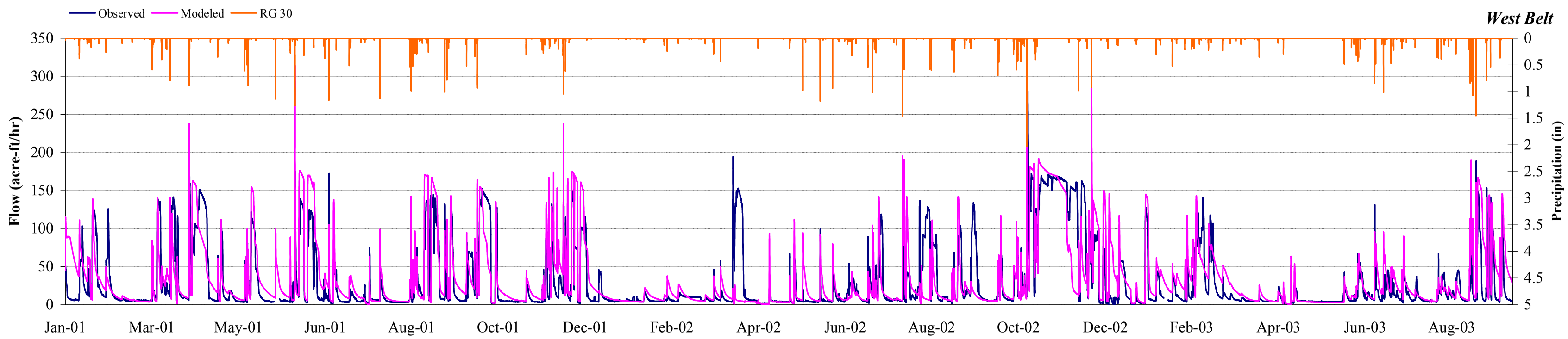


Figure 10.3.6 Comparison of Observed and Modeled Reservoir Discharges

Figure 10.3.7 Observed and Modeled Time Series



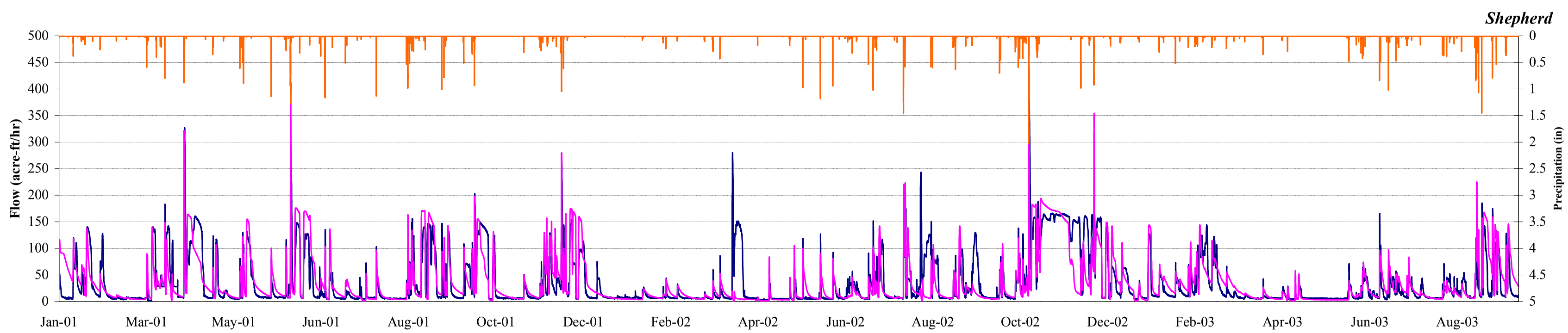
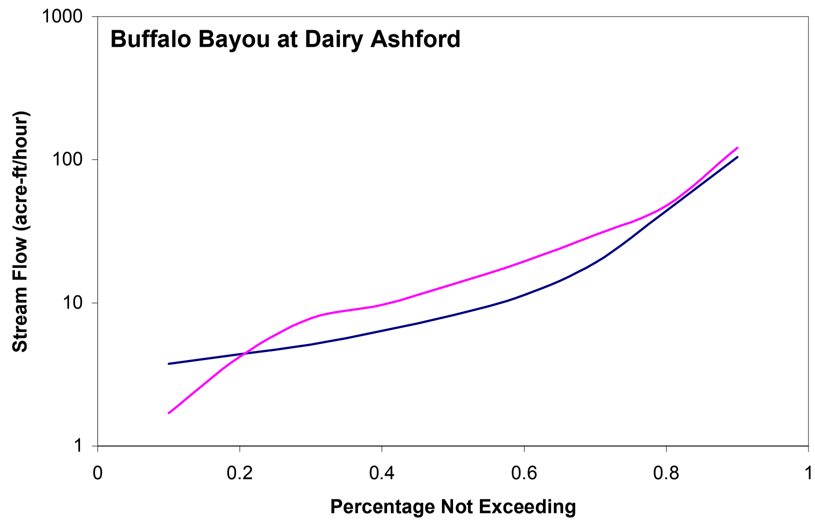
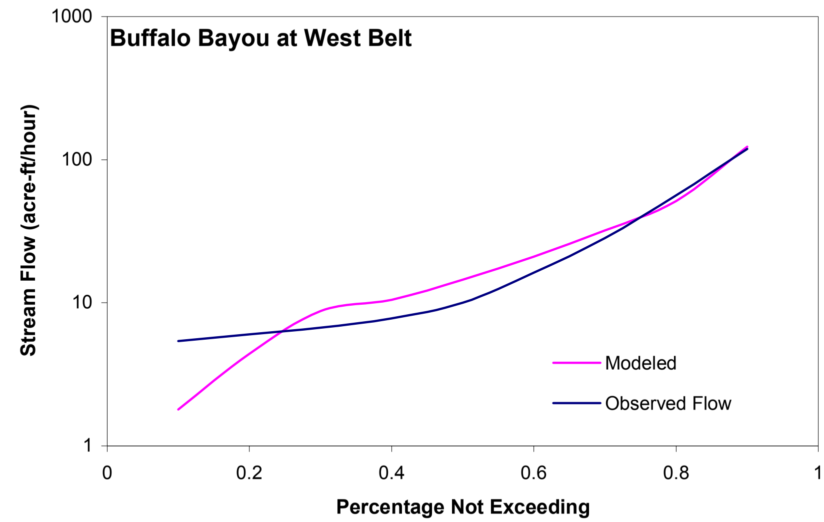


Figure 10.3.7 Observed and Modeled Time Series, continued





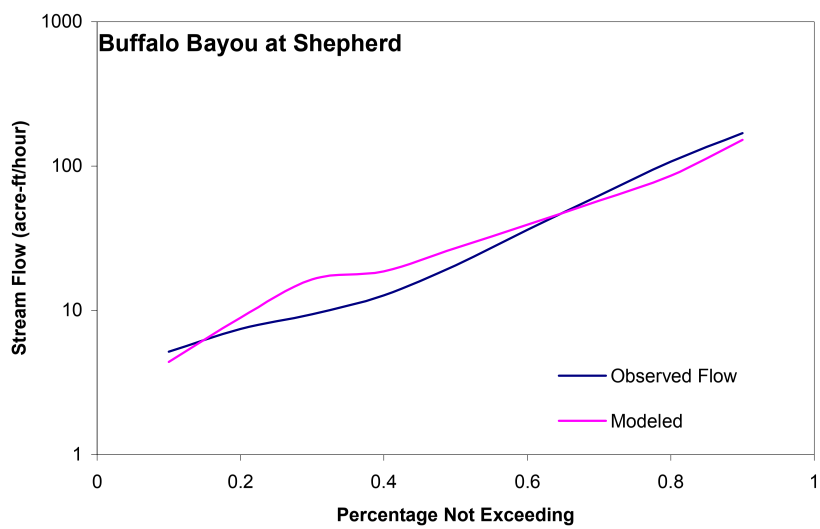
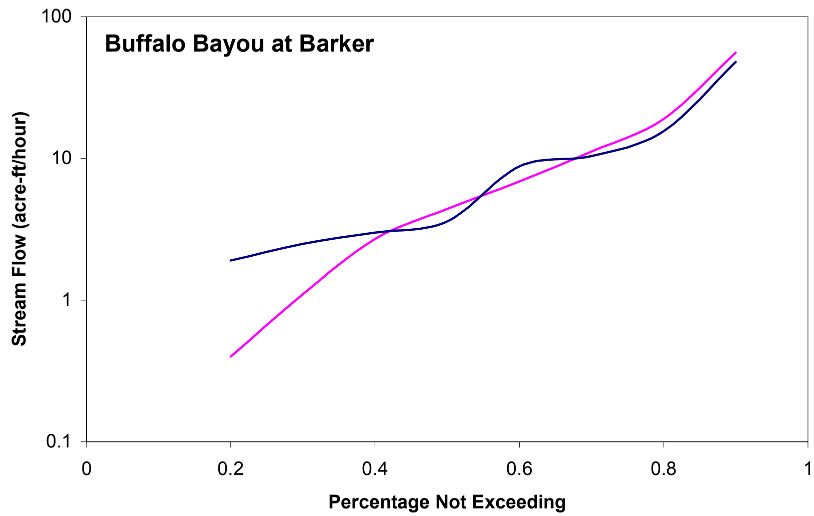


Figure 10.3.8 Comparison of Observed to Modeled Flow Duration Curves for Buffalo Bayou



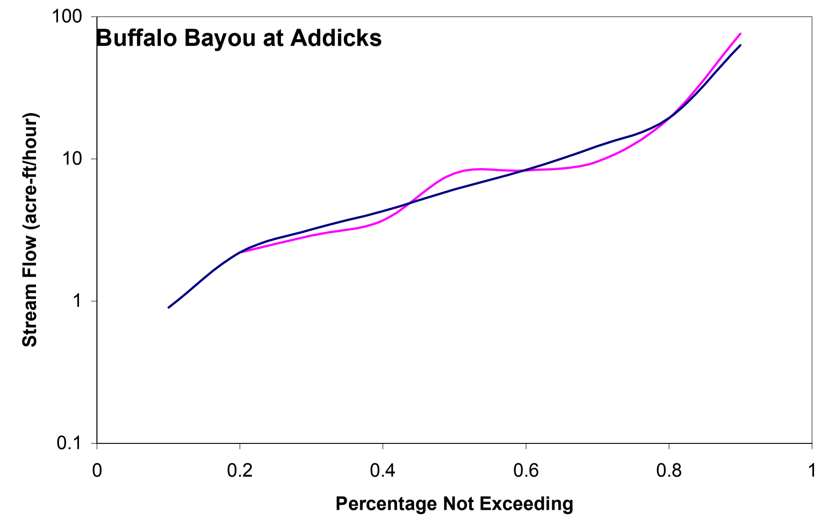


Figure 10.3.8 Comparison of Observed to Modeled Flow Duration Curves for Buffalo Bayou, Continued

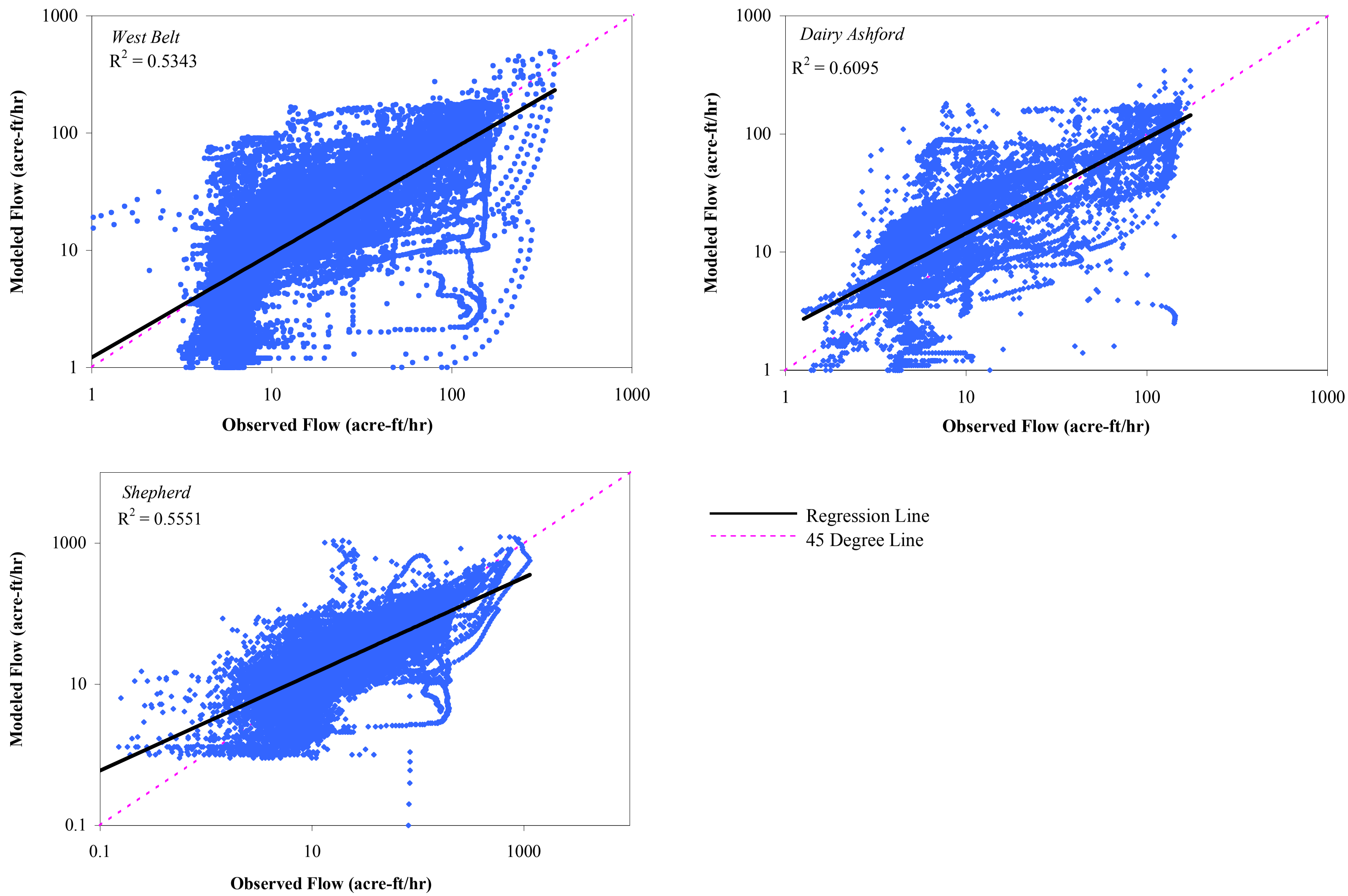


Figure 10.3.9 Comparison of Modeled and Observed Flow in Buffalo Bayou.

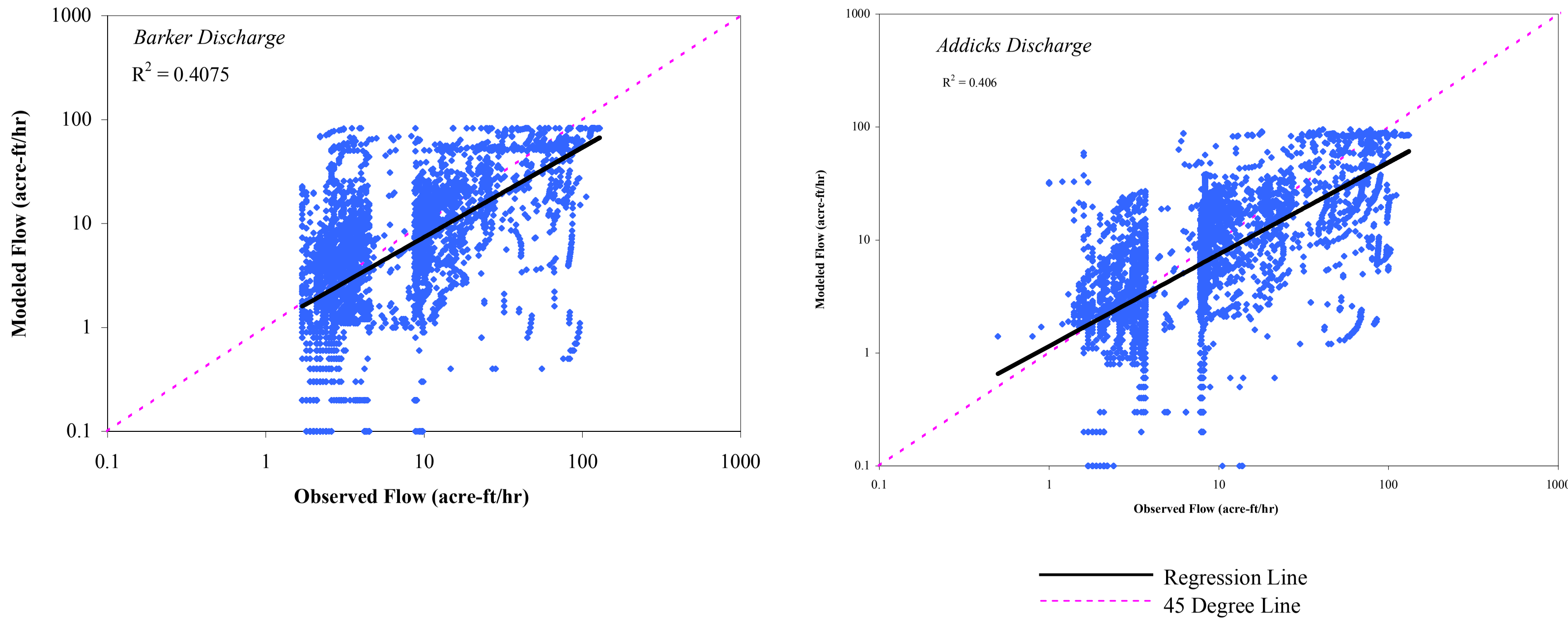


Figure 10.3.9 Comparison of Modeled and Observed Flow in Buffalo Bayou. Continued

Following this effort, the expanded HSPF model was considered hydrologically calibrated and validated for Buffalo Bayou. Additional refinements may be completed to add additional rainfall gages and adjust reservoir gate operation to better match observed flows.

10.3.6 *E. COLI* CALIBRATION

EC calibration was required for the expanded upper watersheds and slight adjustments were made to the previously calibrated parameters for the portion of the model below the reservoirs. The results of the calibration are presented in Table 10.3.7 and Table 10.3.8, which show the results for the reservoir watersheds and lower watersheds, respectively. Plots of the observed and modeled time series are also presented in Figure 10.3.10.

The upper watersheds were calibrated primarily by adjusting non-point source loading. It should be noted that separate calibration and validation assessments could not be performed for the upper watershed as data were only collected stating in 2002, during the validation period. The results shown in Table 10.3.7 are a reasonable match, with errors between observed and modeled geometric means ranging from -54% to 32%. EC concentrations are generally underestimated during low flows, while high flows vary between overestimation and underestimation.

The lower watersheds were calibrated to data from January 1, 2001 to September 30, 2002 and validated using data from October 1, 2002 to September 30, 2003. The errors presented in Table 10.3.8 for the calibration period ranged from -42% to 94% for the overall geometric mean, while during the validation period, the errors ranged from -6% to 763%. These errors are larger than those reported for the Buffalo Bayou model developed in Work Order 5. However, the HSPF models are being continuously refined to improve the model fits.

Table 10.3.7 EC Model Performance for Buffalo Bayou - Upstream of Reservoirs

	Langham Creek AT SH 6			Bear Crk @ Old Greenhouse			Buffalo Bayou @ Peek Rd.		
	Observed	Modeled	Error[1]	Observed	Modeled	Error[1]	Observed	Modeled	Error[1]
Overall GM	545.0	560.2	3%	372.4	482.5	30%	567.7	751.2	32%
High Flow GM [2]	1750.0	6717.3	284%	1383.9	2741.5	98%	4861.6	2541.8	-48%
Low Flow GM [3]	324.5	85.2	-74%	160.1	159.5	0%	316.6	219.8	-31%
Flow < median GM	352.1	193.0	-45%	169.1	153.8	-9%	380.9	332.9	-13%
Flow > median GM	1227.0	4053.3	230%	1216.8	2680.7	120%	1032.9	2545.7	146%
Flow < median RMSE			3.6			4.2			2.6
Flow > median RMSE			2.7			1.8			2.8
RMSE[4]			4.6			4.6			3.8

	S. Mayde Crk @ Groeschek Rd			Mason Crk @ Park Pine Rd.		
	Observed	Modeled	Error[1]	Observed	Modeled	Error[1]
Overall GM	414.7	278.6	-33%	1147.1	531.7	-54%
High Flow GM [2]	1568.4	100.8	-94%	4605.3	2541.8	-45%
Low Flow GM [3]	218.7	156.0	-29%	857.8	62.9	-93%
Flow < median GM	173.9	171.3	-1%	992.9	157.5	-84%
Flow > median GM	1199.5	453.1	-62%	1424.4	3297.3	131%
Flow < median RMSE			2.5			4.5
Flow > median RMSE			10.4			2.9
RMSE[4]			10.7			5.3

Notes:

1 Error calculated as (Observed - Modeled) / Observed

2 High flow GM is geomean of all concentrations where flow is greater than the 70th percentile

3 Low flow GM is geomean of all concentrations where flow is less than the 30th percentile

4 RMSE standard for Root mean square error, calculated $\mathrm{sqrt}(\Sigma(\log(M_i)-\log(O_i))^2)$

Table 10.3.8 EC Model Performance for Buffalo Bayou - Downstream of Reservoir

Calibration (1/1/2001 to 9/30/2002)

	Highway 6			Eldridge			Dairy Ashford			West Belt		
	Observed	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	378	734	94%	415	1181	185%	451	725	61%	1295	1383	7%
High Flow GM [2]	122	1047	757%	164	1027	527%	323	1998	519%	1563	500	-68%
Low Flow GM [3]	633	495	-22%	422	710	68%	404	217	-46%	956	334	-65%
Flow > median GM	122	1047	757%	330	1672	407%	842	1166	38%	1787	519	-71%
Flow < median GM	515	666	29%	471	974	107%	366	619	69%	939	603	-36%
Flow < Median RMSE[4]			4.62			3.39			2.26			1.95
Flow > Median RMSE[4]			1.83			1.78			1.87			1.75
RMSE[4]			5.13			4.05			5.18			3.66

	Briar Forest			Voss			Chimney Rock			Shepherd		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	1324	1240	-6%	1178	1419	20%	1655	1385	-16%	1244	1535	23%
High Flow GM [2]	3180	5535	74%	2152	6315	193%	2562	7140	179%	1392	3954	184%
Low Flow GM [3]	371	445	20%	393	438	12%	822	330	-60%	1385	397	-71%
Flow > median GM	3127	3841	23%	2144	4968	132%	2779	4451	60%	1530	4529	196%
Flow < median GM	560	400	-29%	647	405	-37%	986	431	-56%	1059	662	-37%
Flow < Median RMSE[4]			0.35			0.52			1.41			2.17
Flow > Median RMSE[4]			1.07			2.11			1.64			1.40
RMSE[4]			2.34			2.99			2.64			2.92

	Addicks		
	Observed	**Modeled**	**Error**
Overall GM	527	305	-42%
High Flow GM [2]	912	432	-53%
Low Flow GM [3]	295	116	-61%
Flow > median GM	979	339	-65%
Flow < median GM	284	274	-4%
Low Flow RMSE			1.85
High Flow RMSE			3.82
RMSE			4.64

Notes:

1 Error calculated as (Observed - Modeled) / Observed

2 High flow GM is geomean of all concentrations where flow is greater than the 70th percentile

3 Low flow GM is geomean of all concentrations where flow is less than the 30th percentile

4 RMSE standard for Root mean square error, calculated sqrt($\Sigma(\log(M_i)-\log(O_i))^2$)

Validation (10/1/2002 to 9/30/2003)

	Highway 6			Eldridge			Dairy Ashford			West Belt		
	Observed	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	470.7	1350.1	187%	1039.5	1181.4	14%	553.1	2957.5	435%	551.1	1382.8	151%
High Flow GM [2]	1461.5	10530.1	620%	163.9	1026.9	527%	573.6	14423.5	2414%	500.0	7248.1	1350%
Low Flow GM [3]	160.9	494.8	207%	422.3	709.9	68%	406.5	782.8	93%	603.3	230.3	-62%
Flow < median GM	1190.5	7092.1	496%	330.1	1672.2	407%	752.6	11174.2	1385%	518.8	4568.2	781%
Flow > median GM	160.9	1046.8	550%	470.7	974.1	107%	406.5	782.8	93%	603.3	230.3	-62%
Flow < Median RMSE[4]			0.22			1.73			1.08			1.52
Flow > Median RMSE[4]			0.58			1.77			2.44			1.16
RMSE[4]			0.87			2.50			2.71			2.27

	Briar Forest			Voss			Chimney Rock			Shepherd		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	688.6	997.1	45%	616.1	1142.6	85%	887.8	997.1	12%	3142.5	3343.2	6%
High Flow GM [2]	570.0	3789.7	565%	-	-	-	570.0	3789.7	565%	-	-	-
Low Flow GM [3]	444.1	300.9	-32%	2555.9	341.5	-87%	444.1	300.9	-32%	1000.0	1891.8	89%
Flow > median GM	1067.7	3303.7	209%	1067.7	2555.9	139%	1067.7	3303.7	209%	6980.0	2519.4	-64%
Flow < median GM	444.1	300.9	-32%	444.1	341.5	-23%	444.1	300.9	-32%	1845.9	4037.2	119%
Flow < Median RMSE[4]			0.51			0.37			0.51			0.28
Flow > Median RMSE[4]			0.82			-			0.82			-
RMSE[4]			0.98			1.15			0.98			1.61

	Addicks		
	Observed	**Modeled**	**Error**
Overall GM	442.6	3821.0	763%
High Flow GM [2]	444.1	9519.6	2044%
Low Flow GM [3]	261.2	1355.4	419%
Flow > median GM	607.4	7116.1	1072%
Flow < median GM	261.2	1355.4	419%
Low Flow RMSE			2.33
High Flow RMSE			4.57
RMSE			5.54

Notes:

1 Error calculated as (Observed - Modeled) / Observed

2 High flow GM is geomean of all concentrations where flow is greater than the 70th percentile

3 Low flow GM is geomean of all concentrations where flow is less than the 30th percentile

4 RMSE standard for Root mean square error, calculated sqrt($\Sigma(\log(M_i)-\log(O_i))^2$)

The plots presented in Figure 10.3.10 present the model outputs and compare them with the observed data at each station. Figure 10.3.10 demonstrates that although the model may not be predicting the exact observed value, the model is able to reproduce the overall trends for EC. The model predicts some very low concentrations, however, that are not found in the observed data. The model also overestimates the highest EC concentrations, but this may be due to the fact that observed data are rarely collected during runoff events where these high concentrations are observed. Data collected during this work order and Work Order #2 confirm that EC concentrations do reach these high levels.

10.4 WHITEOAK BAYOU MODEL

The Whiteoak Bayou model was re-calibrated during this work order to include time-varying flows from the WWTPs. The modeling period was also shifted during this work order to accommodate the inclusion of additional EC data. The following sections discuss the flow calibration (10.2.1) and EC calibration (10.2.2).

10.4.1 HYDROLOGIC CALIBRATION/VALIDATION

The Whiteoak Bayou model was recalibrated to incorporate time-varying flow into the hydrology of the model and to adjust the modeling period to January 1, 2001 through September 30, 2003.. There was minimal adjustment of the model parameters required to match the new time-varying flows. The hydrologic calibration for Whiteoak Bayou was conducted in a similar fashion to that conducted for Buffalo Bayou, with a focus on the overall water balance using the same set of criteria. The same set of storms used for Buffalo Bayou were also used for Whiteoak

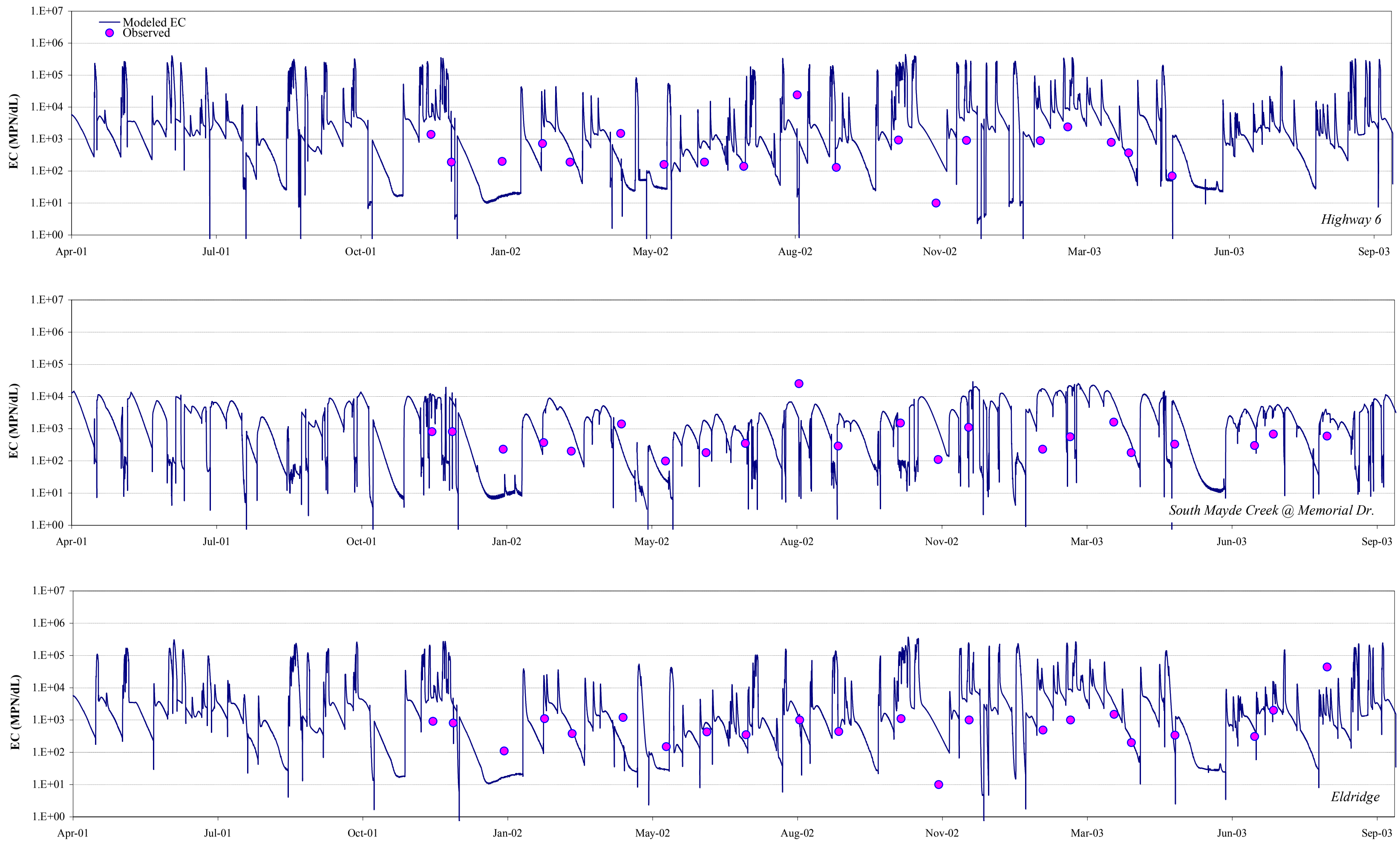


Figure 10.3.10 Model and Observed EC concentrations for Buffalo Bayou

Figure 10.3.10 Model and Observed EC concentrations for Buffalo Bayou, continued

Figure 10.3.10 Model and Observed EC concentrations for Buffalo Bayou, continued

Bayou. The stations used for hydrologic calibration and validation were Alabanson, Cole Creek, Brickhouse Gully, and Heights.

The results of the hydrologic calibration/validation are presented in Table 10.4.1. The results indicate that the overall fit between the modeled data and observed data is fairly reasonable during the calibration period. The specified goals for calibration are met everywhere except for the storm volumes at Alabonson and Brickhouse Gully. The Brickhouse Gully flow gage typically records only high flows while the Alabonson gage began providing readings in 2002. As these two gages are not the most reliable, it was determined that the calibration was adequate.

One potential area of concern is the large discrepancy between the calibration and validation runs. The validation flows have much greater errors than those observed during calibration. Since the validation is intended as a confirmation of the ability of the model to simulate the bayou conditions, the large magnitude of the errors observed in the validation run was investigated more closely. Based upon an initial evaluation, the problem appears to stem from the relatively low rainfall gage density across the watershed and not the inability of the model to simulate the system well. To address the problem associated with rainfall, more rainfall gages will be added to the simulation in the future.

Figure 10.4.1 shows the observed rainfall, flow, and the modeled flow time series at Alabonson, Brickhouse Gully, Cole Creek and Heights Blvd. These plots show a good general match between the observed and modeled data. Figure 10.4.2 presents flow duration curves that were developed for each gage. These plots demonstrate that low flows are overestimated by the model to some extent at Whiteoak Bayou at Heights, while the low flows at Cole Creek at Diehl and Brickhouse Gully are somewhat underestimated. Plots of modeled data versus observed data

Table 10.4.1 Hydrology Model Performance Summary for Whiteoak Bayou

Calibration (1/1/2001 - 9/30/2002) [4]

Data Source	Location	Total Volume[1]	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Cole Creek	4.30E+04	7.6	2.3	2.68	9.67E+03	1.52E+04
	Heights	2.75E+05	24.9	2.7	3.62	9.45E+04	1.21E+05
	Alabonson	3.09E+04	5.3	1.2	1.32	4.21E+03	8.54E+03
	Brickhouse Gully	4.93E+04	2.0	0.2	0.28	2.72E+04	3.00E+04
Modeled	Cole Creek	4.12E+04	10.9	1.1	1.33	1.00E+04	1.53E+04
	Heights	3.14E+05	26.6	5.9	6.37	7.32E+04	1.14E+05
	Alabonson	3.74E+04	5.7	1.2	1.32	6.62E+03	1.14E+04
	Brickhouse Gully	4.34E+04	3.0	0.1	0.17	1.18E+04	1.58E+04
Error[3]	Cole Creek	-4%	43%	-50%	-50%	3%	1%
	Heights	14%	7%	113%	76%	-22%	-6%
	Alabonson	21%	7%	-1%	0%	57%	34%
	Brickhouse Gully	-12%	49%	-55%	-38%	-56%	-47%

Validation (10/1/2002 - 9/30/2003) [4]

Data Source	Location	Total Volume[1]	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Cole Creek	1.35E+04	18.3	3.7	4.19	4.56E+03	2.64E+03
	Heights	1.43E+05	33.3	3.0	3.53	3.62E+04	2.91E+04
	Alabonson	5.90E+04	10.1	1.4	1.70	1.73E+04	1.05E+04
	Brickhouse Gully	2.35E+04	3.0	0.2	0.34	6.99E+03	3.77E+03
Modeled	Cole Creek	2.08E+04	33.5	1.9	4.56	5.82E+03	4.78E+03
	Heights	2.12E+05	42.6	6.0	7.50	4.72E+04	4.45E+04
	Alabonson	7.30E+04	15.4	1.2	1.85	2.01E+04	1.29E+04
	Brickhouse Gully	3.01E+04	4.9	0.1	0.28	7.41E+03	7.26E+03
Error[3]	Cole Creek	54%	83%	-49%	9%	28%	81%
	Heights	49%	28%	102%	113%	30%	53%
	Alabonson	24%	52%	-12%	9%	16%	23%
	Brickhouse Gully	28%	64%	-55%	-17%	6%	92%

Notes:

[1] Volumes are in acre-ft/hr

[2] Storm volumes were calculated using dates presented in Table 10.3.5

[3] Error percentage calcualted as (Model Value - USGS Value) / USGS Value, 0% indicates perfect matcl

[4] Flow statistics compiled for gages only when observed flow available

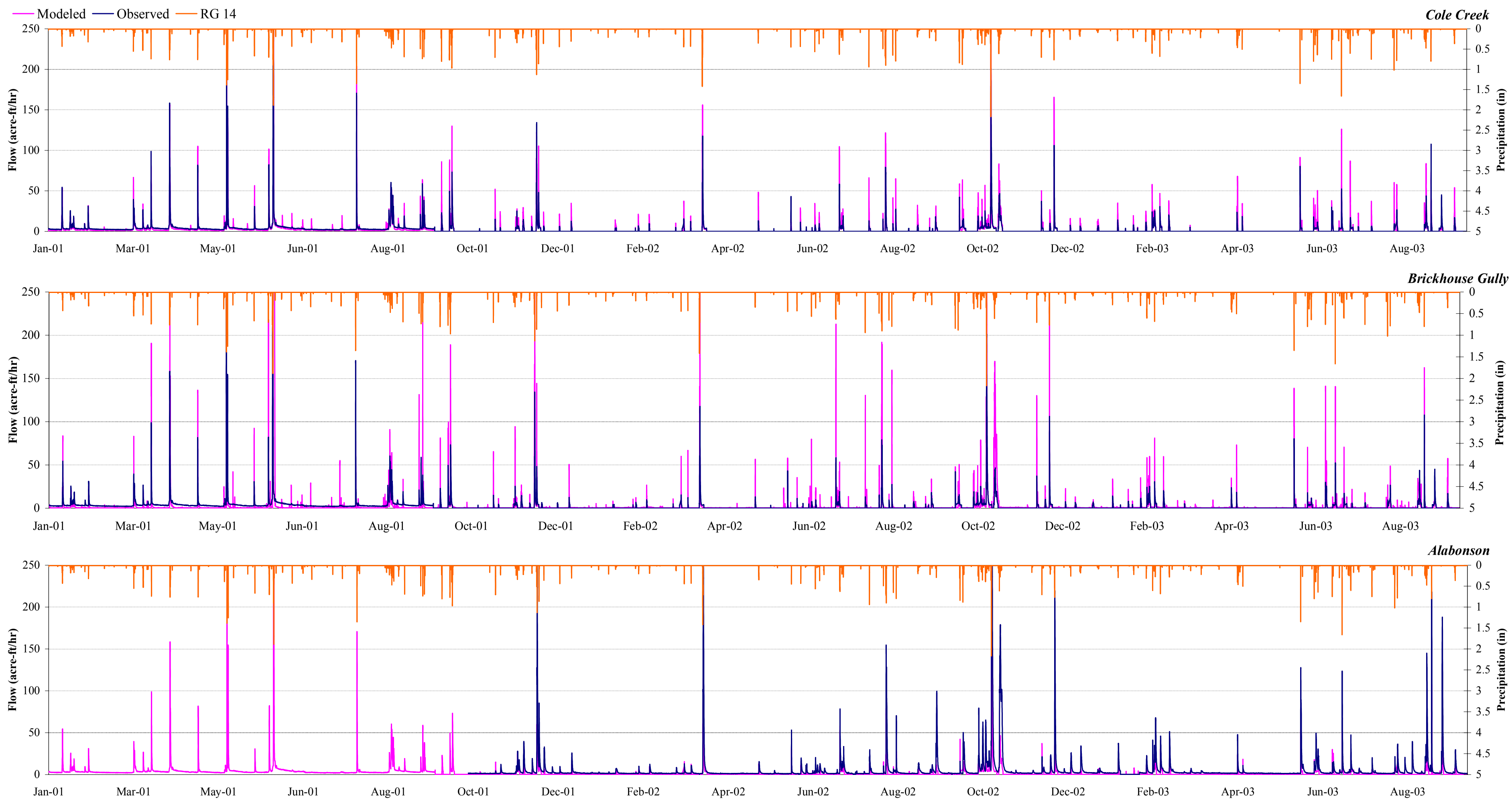


Figure 10.4.1 Observed and Modeled Time Series for Whiteoak Bayou

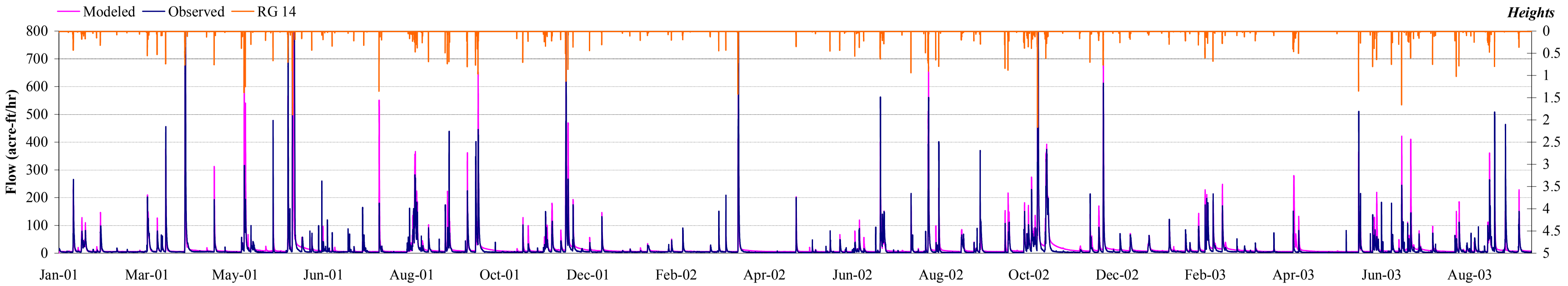


Figure 10.4.1 Observed and Modeled Time Series for Whiteoak Bayou, continued

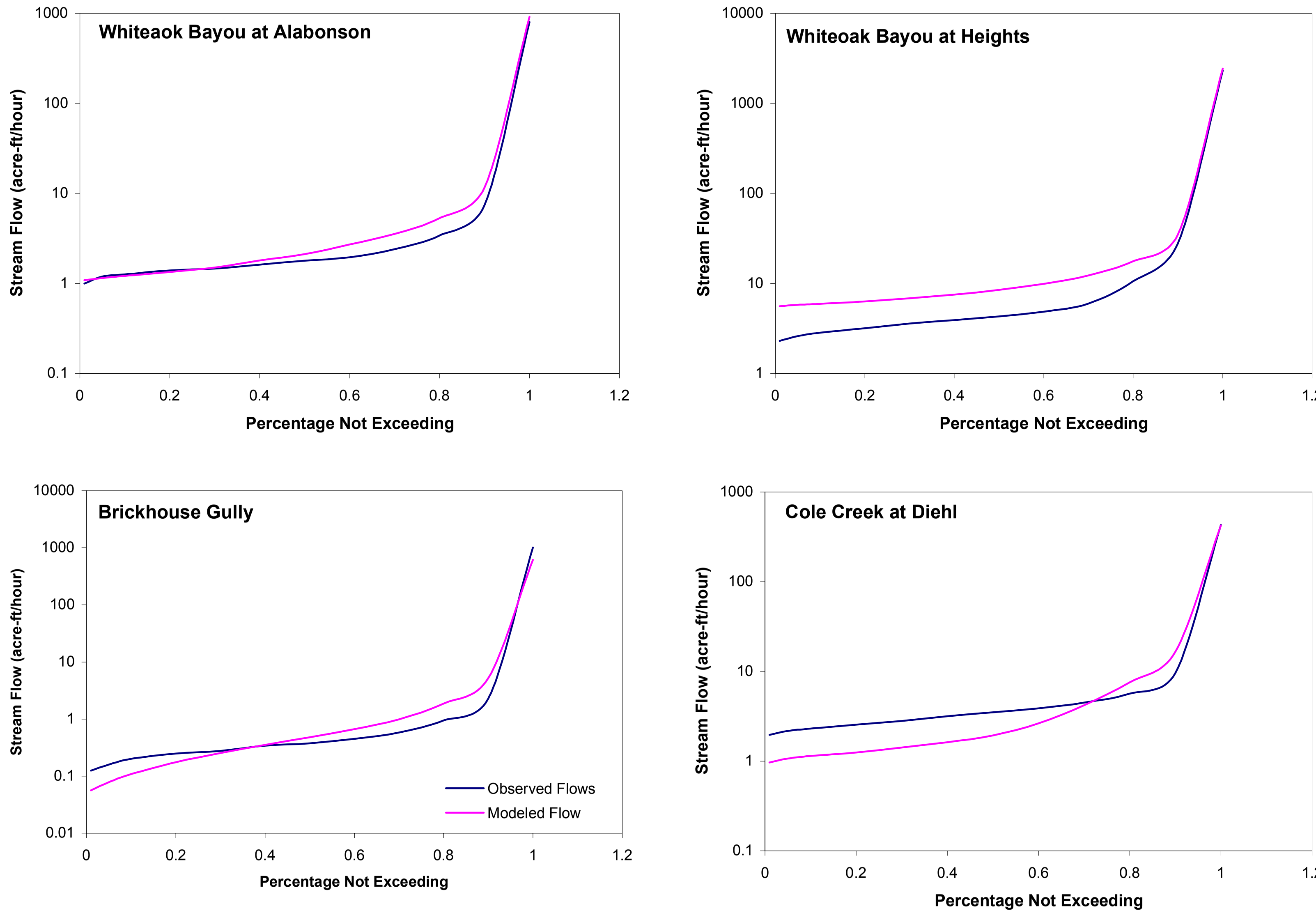


Figure 10.4.2 Comparison of Observed to Modeled Flow Duration Curves for Whiteoak Bayou

are presented in plots for individual stations in Figure 10.4.3. The r^2 values reported in these one-to-one plots range between 0.64 and 0.79, indicating a very good fit between modeled and observed data.

Following this effort, the HSPF model was considered hydrologically calibrated and validated for Whiteoak Bayou. Additional refinements will be undertaken in the future to add additional rainfall gages to improve the validation runs.

10.4.2 *E. COLI* CALIBRATION

EC calibration was required to calibrate the model to the EC data collected over the past three years. Slight adjustments were made to the calibration to improve the fit obtained when using fecal coliform data for calibration. The results of the calibration are presented in Table 10.4.2 and plots of the observed and modeled time series are also presented in Figure 10.4.4.

The results shown in Table 10.4.2 are a reasonable match, with errors between observed and modeled geometric means ranging from -28% to 17%. EC concentrations are generally underestimated during low flows, while high flows vary between overestimation and underestimation. It can be seen that the model can reproduce the trends in the observed data as shown in Figure 10.4.4, with some exceptions. For example, the low concentrations in Cole Creek predicted by the model do not match the observed data, with the model predicting higher concentrations than those observed. Again, model refinements will continue to improve model performance.

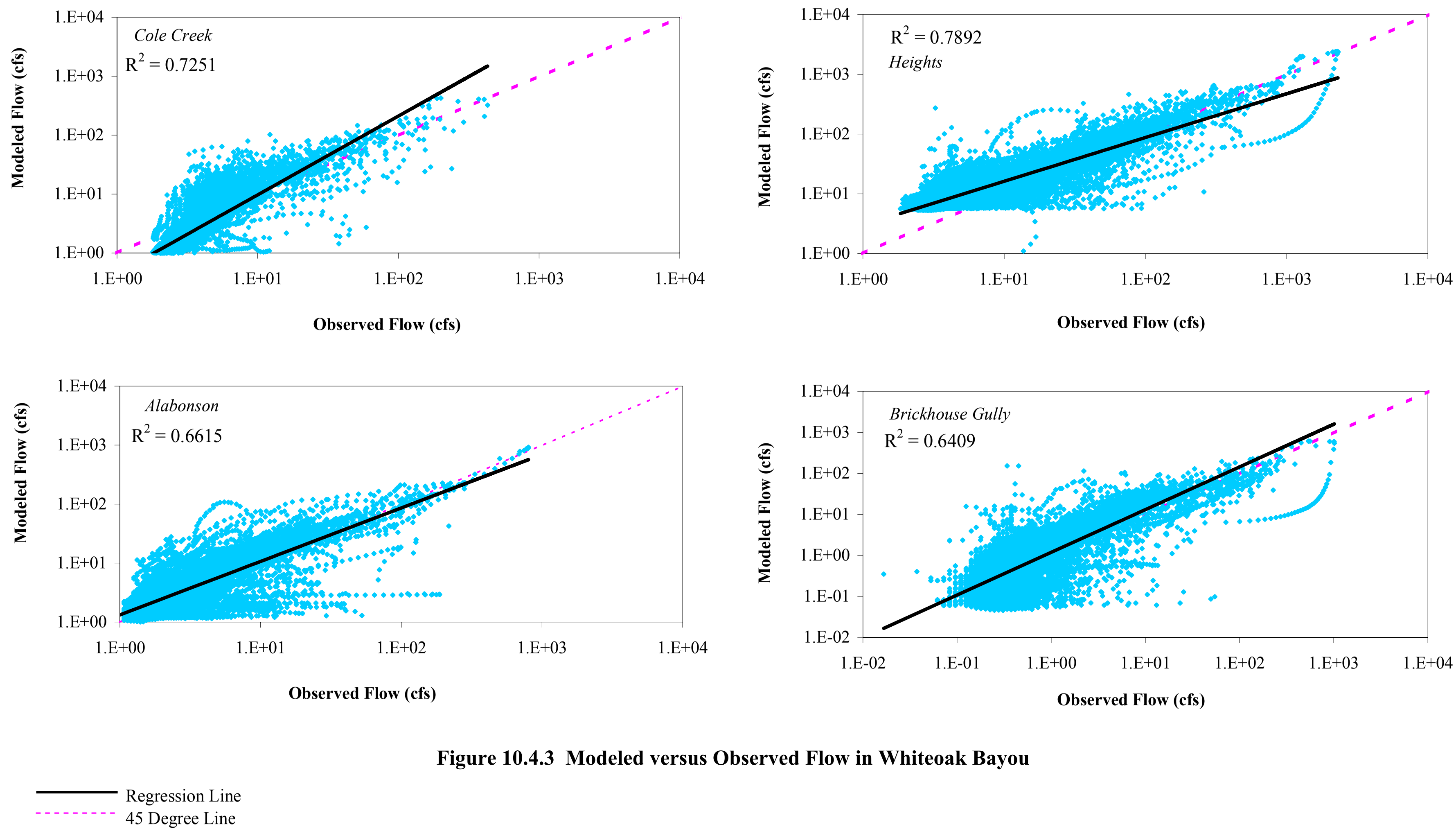


Figure 10.4.3 Modeled versus Observed Flow in Whiteoak Bayou

Table 10.4.2 EC Model Performance for Whiteoak Bayou

Calibration (1/1/2001 to 9/30/2002)

	Heights			Little WOB			Ella		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	3275.8	847.3	-74%	8758.6	6280.7	-28%	4481.0	4150.9	-7%
High Flow GM [2]	6513.3	2351.7	-64%	6448.3	2637.6	-59%	5828.5	10737.3	84%
Low Flow GM [3]	1867.6	513.7	-72%	9064.9	5659.4	-38%	3028.0	2356.4	-22%
Flow < median GM	9385.5	1766.7	-81%	8495.0	8199.3	-3%	5271.5	8290.9	57%
Flow > median GM	1812.1	560.5	-69%	8984.6	5029.6	-44%	4083.7	2795.5	-32%
Flow < Median RMSE[4]			3.8			3.0			2.0
Flow > Median RMSE[4]			39.1			1.3			1.6
RMSE[4]			8.8			3.3			2.5

	Cole Creek			W43RD			RCH 1		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	3731.6	5778.5	55%	3207.3	3263.5	2%	5322.4	5390.5	1%
High Flow GM [2]	6857.7	12432.8	81%	8246.2	23443.0	184%	20305.3	1991.7	-90%
Low Flow GM [3]	1486.1	3452.0	132%	1581.6	1757.1	11%	5268.9	1755.2	-67%
Flow > median GM	11264.3	10722.9	-5%	4081.7	15052.6	269%	8113.6	7527.9	-7%
Flow < median GM	1486.1	3452.0	132%	2930.1	1839.5	-37%	3745.6	4080.9	9%
Flow < Median RMSE[4]			2.7			1.7			5.9
Flow > Median RMSE[4]			2.2			1.1			3.0
RMSE[4]			3.4			2.1			6.6

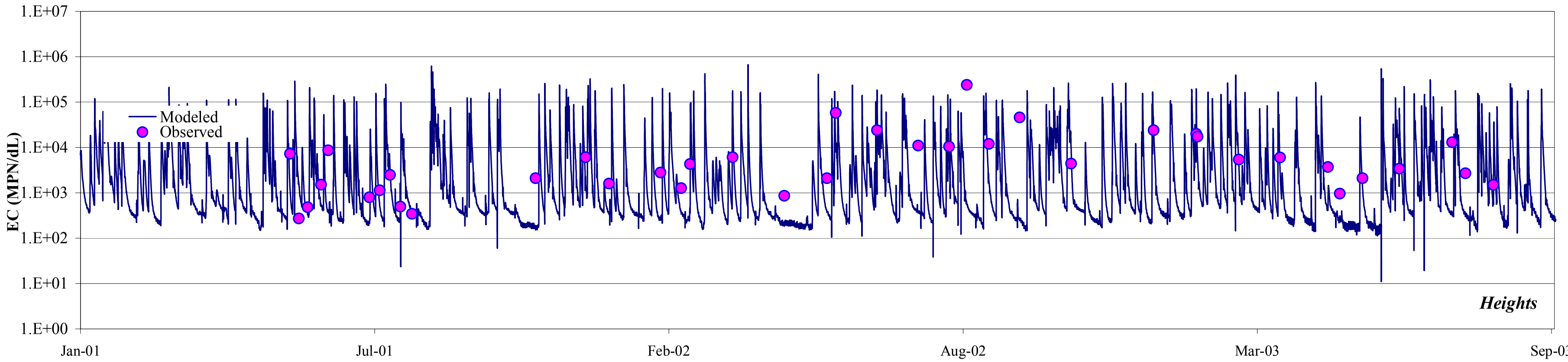
Notes:
1 Error calculated as (Observed - Modeled) / Observed
2 High flow GM is geomean of all concentrations where flow is greater than the 70th percentile
3 Low flow GM is geomean of all concentrations where flow is less than the 30th percentile
4 RMSE standard for Root mean square error, calculated sqrt($\Sigma(\log(M_i)-\log(O_i))^2$)

Validation (10/12002 to 9/30/2003)

	Heights			Little WOB			Ella		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	5968.3	2601.6	-56%	13012.2	9309.4	-28%	2330.4	2723.7	17%
High Flow GM [2]	8274.0	27571.2	233%	13711.5	26417.5	93%	3488.0	7754.5	122%
Low Flow GM [3]	9828.5	577.8	-94%	19899.7	6893.0	-65%	309.8	631.7	104%
Flow < median GM	8683.3	7766.6	-11%	11505.2	13280.9	15%	4030.2	4566.3	13%
Flow > median GM	3620.2	605.2	-83%	16644.2	4574.2	-73%	779.2	969.1	24%
Flow < Median RMSE[4]			12.8			2.1			0.5
Flow > Median RMSE[4]			6.4			2.1			2.3
RMSE[4]			8.7			3.0			2.3

	Cole Creek			W43RD			RCH 1		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall GM	1921.1	4495.7	134%	1406.3	2528.1	80%	2876.1	4638.2	61%
High Flow GM [2]	1649.7	14945.2	806%	1688.2	5812.7	244%	5154.2	20061.7	289%
Low Flow GM [3]	707.4	3310.1	368%	375.5	1323.6	252%	1578.3	50.9	-97%
Flow > median GM	2676.6	6406.0	139%	2850.8	3843.9	35%	4154.6	12526.9	202%
Flow < median GM	1378.9	3155.1	129%	523.0	1406.1	169%	1718.6	1154.1	-33%
Flow < Median RMSE[4]			1.8			1.4			3.5
Flow > Median RMSE[4]			2.5			2.1			1.9
RMSE[4]			3.1			2.5			4.0

Notes:
1 Error calculated as (Observed - Modeled) / Observed
2 High flow GM is geomean of all concentrations where flow is greater than the 70th percentile
3 Low flow GM is geomean of all concentrations where flow is less than the 30th percentile
4 RMSE standard for Root mean square error, calculated sqrt($\Sigma(\log(M_i)-\log(O_i))^2$)



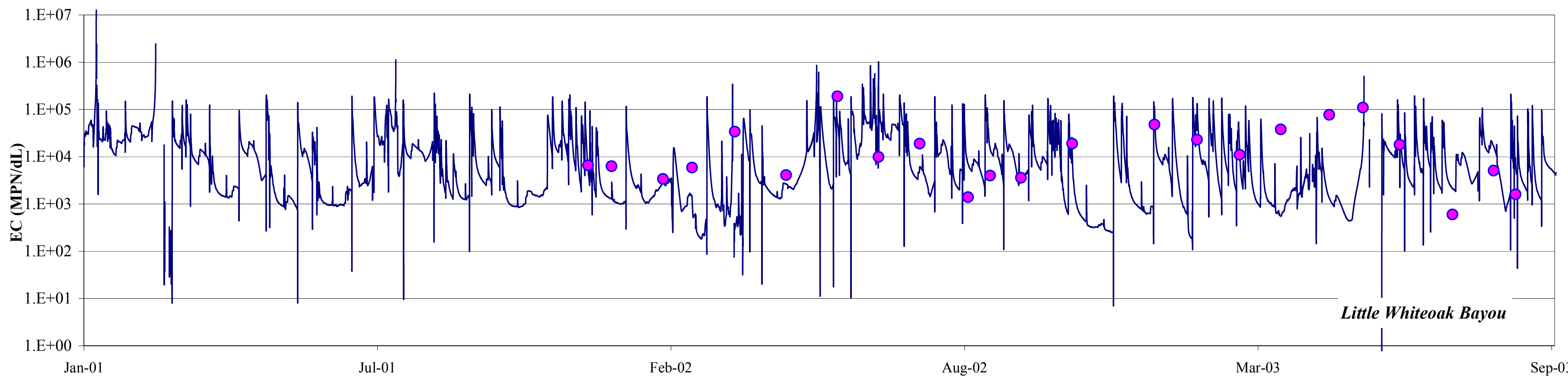


Figure10.4.4 Model and Observed EC concentrations for Whiteoak Bayou

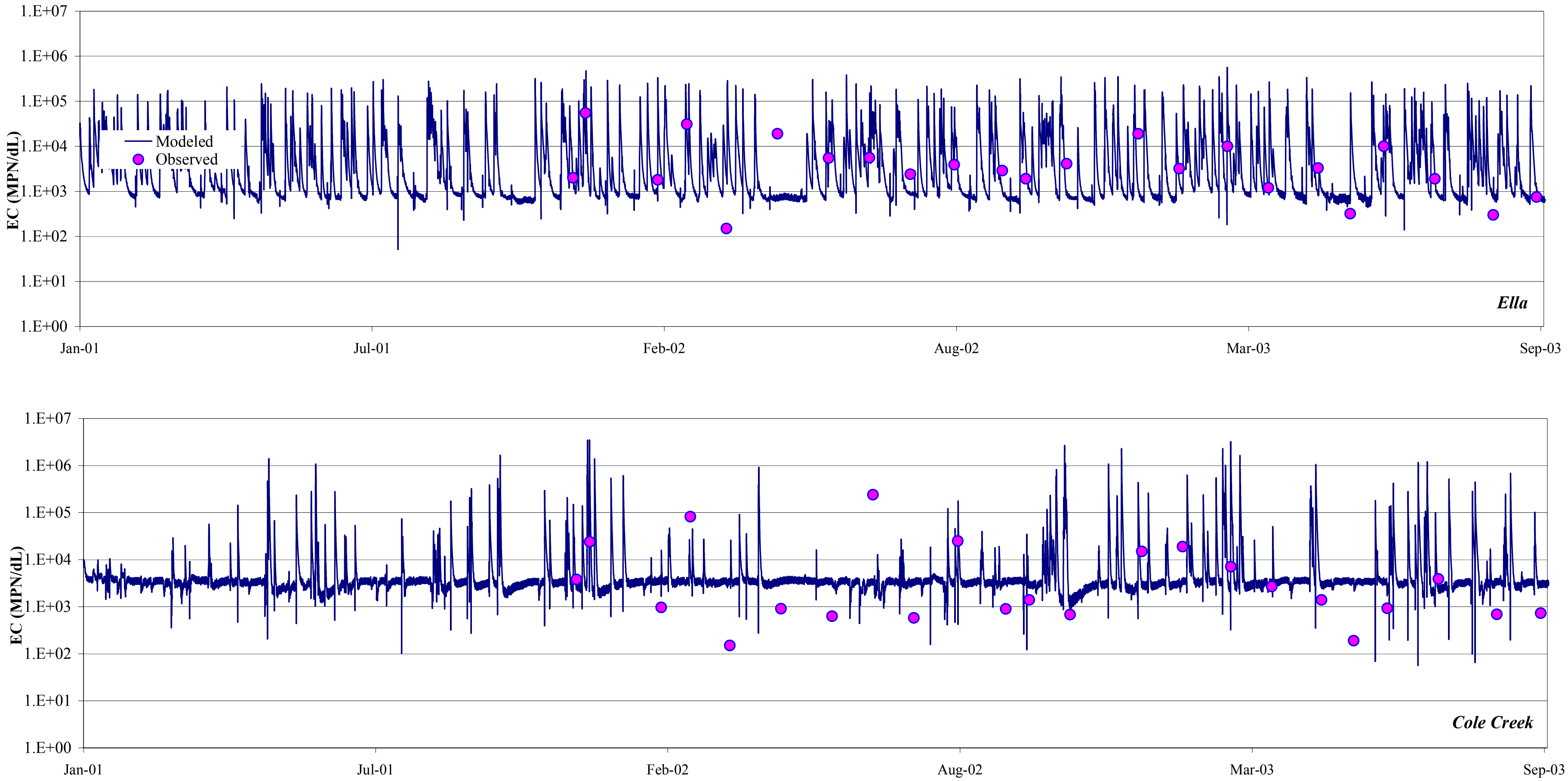


Figure10.4.4 Model and Observed EC concentrations for Whiteoak Bayou, continued

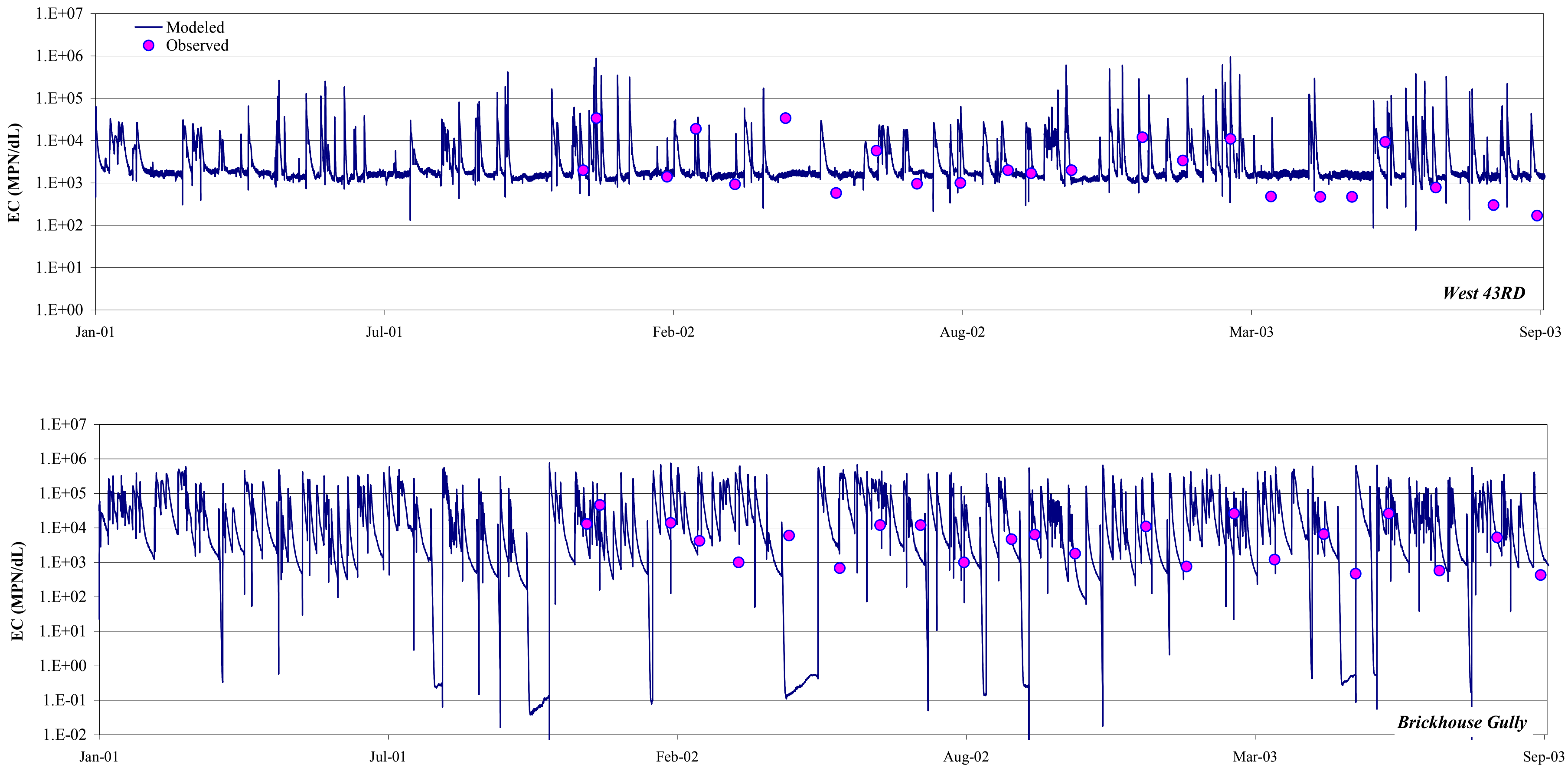


Figure 10.4.4 Model and Observed EC concentrations for Whiteoak Bayou, continued

CHAPTER 11

QUALITY ASSURANCE PROJECT PLAN AND QUALITY CONTROL

The Quality Assurance Project Plan (QAPP) is a document that describes the tasks, management structure and policies that will be implemented in the monitoring program for this project. The QAPP will ensure that the data collected under this work order will be reliable, scientifically valid and legally defensible. In addition, data quality checks were also completed to demonstrate compliance with the QAPP. These data checks are described in more detail below.

11.1 QAPP

The first draft of the QAPP was submitted on December 12, 2003 to the TCEQ. Comments on the draft QAPP were received on January 23, 2004 and the QAPP was revised and resubmitted on February 27, 2004. The QAPP was sent to the US EPA for approval on March 26, 2004. The final approval for the QAPP was received on June 4, 2004. The QAPP is attached as Appendix I.

11.2 QUALITY CONTROL

This section details the quality control/quality assurance (QA/QC) tasks undertaken to meet the data quality objectives (DQOs) stated in the QAPP, related to both field and laboratory analysis.

11.2.1 FIELD QA/QC

In the field, both equipment blanks and field splits were collected to document adherence to the DQOs in the QAPP. Equipment blanks were collected by taking previously prepared sterile water and adding it to the sterile beakers used to collect EC samples by UH. The sterile water was swirled inside the bucket to touch all surfaces. The water was then poured into a Whirl-pak bag. The equipment blank was stored on ice and analyzed for EC in the same manner as water quality samples. Table 11.1 presents the results of equipment blanks collected during WWTP and Reservoir sampling. There were no instances when *E. coli* was detected in the equipment blanks, thus demonstrating that no contamination of the beakers occurred.

Field splits, which are used to assess the variability of sampling handling, preservation, and the analytical process, were also performed on field samples. At locations where field splits were collected, the sample was collected in a single container and then poured into two separate containers that were analyzed individually. The QAPP requires that the relative percent difference (RPD) be calculated using equation 11.1 and to be within 20% for chemical and physical constituents. The results from field splits are presented in Table 11.2.

$$\mathbf{RPD = \{ (X_1 - X_2) / \langle (X_1 + X_2)/2 \rangle \} * 100} \qquad \text{(Eqn 11-1)}$$

For microbiological constituents, the performance limits are specified by Equation 11.2, where R_{log} is the difference in the natural log of splits for the first 15 positive (i.e. both samples are greater than the detection limit) split samples. If the result for X_1 or X_2 is less than the detection limit, then ½ the detection limit was used in calculating the logarithm. The performance criterion was updated periodically by recalculating using the most recent set of 15 positive split analyses. The results of the microbiological field splits are presented in Table 11.3.

$$\mathbf{3.27\ \Sigma R_{log}/n} \qquad \text{(Eqn 11-2)}$$

As shown in Table 11.2, the variability in RPD for samples collected prior to July 12, 2004 is generally higher than those after that date with several failures to meet the 20% criterion. This is due to the fact that field duplicates, rather than field splits, were being collected prior to that date. The methodology used to collect field duplicates involves collecting two *separate* samples rather than collecting one sample and splitting it into two containers for analysis. The field duplicate is more an indication of variability in the water being sampled rather than the handling and analytical procedures. Once proper field splits were collected, the number of samples that did not meet the RPD criteria decreased. Only two samples failed the criterion, and these were wet weather samples. Samples collected during wet weather are inherently non-homogenous and have a high level of variability, even when the sample is collected in one single container. Therefore, these failures were not considered to compromise the data quality.

The results from bacteria field split analysis are shown in Table 11.3. The first 15 splits were used to calculate the precision criteria. The remaining 8 samples were not greater than the criteria. Thus, no failures were noted in the bacteria data.

11.2.2 LABORATORY QA/QC

The laboratory analysis of *E. coli* was conducted at the University of Houston and PBS&J Laboratories. As such, laboratory QA/QC was also required to document compliance with the QAPP. The laboratory was required to complete lab blanks, which documented the water used for dilutions was sterile and free of any contamination. The results of the lab blanks are shown in Table 11.4; contamination was never detected.

Table 11.1 Field Equipment Blank Results

Date	Sample ID	EC Result (MPN/dL)
6/14/2004	Equipment Blank	0
6/21/2004	Equipment Blank	0
6/22/2004	Equipment Blank	0
6/29/2004	Equipment Blank	0
6/30/2004	Equipment Blank	0
7/13/2004	Equipment Blank	0
7/15/2004	Equipment Blank	0
7/22/2004	Equipment Blank	0
7/24/2004	Equipment Blank	0
7/24/2004	Equipment Blank	0
7/24/2004	Equipment Blank	0
7/24/2004	Equipment Blank Barker	0
7/24/2004	Equipment Blank Barker	0
7/25/2004	Equipment Blank Addicks	0
8/9/2004	Equipment Blank #1	0
8/9/2004	Equipment Blank #2	0
8/19/2004	Equipment Blank Addicks	0
8/19/2004	Equipment Blank Barker Discharge	0
8/19/2004	Equipment Blank BB @ West	0
8/19/2004	Equipment Blank DA	0
8/19/2004	Equipment Blank S. Maytde	0
8/27/2004	Equipment Blank Addicks	0
8/27/2004	Equipmnet Blank Barker	0
8/28/2004	Equipment Blank Addicks	0
8/28/2004	Equipment Blank Addicks Pool	0
8/28/2004	Equipment Blank Barker	0
8/28/2004	Equipment Blank Bear Crk	0
8/28/2004	Equipment Blank Langham	0
8/28/2004	Equipment Blank Mason Creek	0
8/28/2004	Equipment Blank Westheimer	0
8/28/2004	Sterility Check	0
8/28/2004	Sterility Check	0

Table 11.2 Field Sample Split Results

Date	Parameter	Task	Sample ID	Result 1 (mg/L)	Result 2 (mg/L)	RPD	RPD < 20?
6/15/2004	Chlorine	9	10495-139-I	< 0.02	0.3	187.88	N
6/15/2004	Phosphorous	9	10495-139-I	0.32	0.95	99.21	N
6/15/2004	TDS	9	10495-139-I	484.00	487.00	0.62	Y
6/15/2004	TSS	9	10495-139-I	6.00	7.00	15.38	Y
6/30/2004	Chlorine	9	12795-001-D	0.12	< 0.02	169.23	N
6/30/2004	Phosphorous	9	12795-001-D	7.45	9.16	20.59	N
6/30/2004	TDS	9	12795-001-D	686.00	696.00	1.45	Y
6/30/2004	TSS	9	12795-001-D	12.0	14.0	15.38	Y
6/30/2004	Chlorine	9	12795-001-I	1.10	0.97	12.56	Y
6/30/2004	Phosphorous	9	12795-001-I	5.44	5.58	2.54	Y
6/30/2004	TDS	9	12795-001-I	809.00	783.00	3.27	Y
6/30/2004	TSS	9	12795-001-I	14.00	10.40	29.51	N
7/12/2004	Chlorine	9	12516-001-D	0.13	0.12	8.00	Y
7/12/2004	Phosphorous	9	12516-001-D	8.00	10.44	26.46	N
7/12/2004	TDS	9	12516-001-D	519.00	413.00	22.75	N
7/12/2004	TSS	9	12516-001-D	7.20	34.00	130.10	N
7/25/2004	TSS	12-Wet	Buf @ West - Rnd 1	70.00	73.00	4.20	Y
7/25/2004	TDS	12-Wet	Buf @ West - Rnd 1	303.00	292.00	3.70	Y
7/25/2004	Phosphorous	12-Wet	Buf @ West - Rnd 1	2.41	2.06	15.66	Y
7/25/2004	TSS	12-Wet	Dairy Ash - Rnd 3-DUP	323.00	365.00	12.21	Y
7/25/2004	TDS	12-Wet	Dairy Ash - Rnd 3-DUP	142.00	130.00	8.82	Y
7/25/2004	Phosphorous	12-Wet	Dairy Ash - Rnd 3-DUP	0.95	1.07	11.88	Y
8/5/2004	Chlorine	9	10495-109-E	0.20	0.18	10.53	Y
8/5/2004	Phosphorous	9	10495-109-E	5.26	5.18	1.53	Y
8/5/2004	TDS	9	10495-109-E	4.00	4.00	0.00	Y
8/5/2004	TSS	9	10495-109-E	547.00	565.00	3.24	Y
8/9/2004	TDS	12-Dry	Barker Dischage	442.00	444.00	0.45	Y
8/9/2004	TSS	12-Dry	Barker Dischage	103.00	104.00	0.97	Y
8/9/2004	Phosphorous	12-Dry	Bear Creek	3.19	3.46	8.12	Y
8/9/2004	DOC	12-Dry	Turkey Creek	11.40	11.70	2.60	Y
8/9/2004	TOC	12-Dry	Turkey Creek	4.00	4.00	0.00	Y
8/19/2004	Phosphorous	12-Wet	Barker Dis - Rnd 5	2.58	2.84	9.59	Y
8/19/2004	TDS	12-Wet	Barker Dis - Rnd 5	532.00	493.00	7.61	Y
8/19/2004	TSS	12-Wet	Barker Dis - Rnd 5	152.00	161.00	5.75	Y
8/19/2004	TDS	12-Wet	Bear Creek - Rnd 2	245.00	242.00	1.23	Y
8/19/2004	TSS	12-Wet	Bear Creek - Rnd 2	106.00	114.00	7.27	Y
8/19/2004	Phosphorous	12-Wet	Bear Creek - Rnd 2	1.76	1.82	3.35	Y
8/19/2004	Phosphorous	12-Wet	Bear Creek - Rnd 4	2.43	2.45	0.82	Y
8/19/2004	TDS	12-Wet	Bear Creek - Rnd 4	515.00	454.00	12.59	Y
8/19/2004	TSS	12-Wet	Bear Creek - Rnd 4	29.00	35.00	18.75	Y
8/19/2004	Phosphorous	12-Wet	Dairy Ash - Rnd 3	2.35	2.01	15.60	Y
8/19/2004	TDS	12-Wet	Dairy Ash - Rnd 3	336.00	347.00	3.22	Y
8/19/2004	TSS	12-Wet	Dairy Ash - Rnd 3	203.00	275.00	30.13	N
8/27/2004	Phosphorous	12-Dry	Addicks Discharge	3.86	3.93	1.80	Y
8/27/2004	Phosphorous	12-Wet	Addicks Pool - Rnd 3	4.39	4.48	2.03	Y
8/27/2004	TDS	12-Wet	Addicks Pool - Rnd 3	435.00	419.00	3.75	Y
8/27/2004	TSS	12-Wet	Addicks Pool - Rnd 3	26.00	27.00	3.77	Y
8/27/2004	DOC	12-Dry	Barker Dischage	9.01	8.85	1.79	Y
8/27/2004	TDS	12-Dry	Barker Dischage	308.00	330.00	6.90	Y
8/27/2004	TSS	12-Dry	Barker Dischage	120.00	104.00	14.29	Y

Date	Parameter	Task	Sample ID	Result 1 (mg/L)	Result 2 (mg/L)	RPD	RPD < 20?
8/27/2004	TOC	12-Dry	Barker Dischage	10.10	10.50	3.88	Y
8/27/2004	Phosphorous	12-Dry	Barker Dischage	3.89	3.89	0.00	Y
8/27/2004	DOC	12-Dry	Bear Creek	7.79	8.17	4.76	Y
8/27/2004	TSS	12-Dry	Bear Creek	8.00	10.00	22.22	N
8/27/2004	TDS	12-Dry	Bear Creek	404.00	406.00	0.49	Y
8/27/2004	TOC	12-Dry	Bear Creek	8.82	8.82	0.00	Y
8/28/2004	Phosphorous	12-Wet	Bear Creek - Rnd 4	2.02	1.96	3.02	Y
8/28/2004	TDS	12-Wet	Bear Creek - Rnd 4	435.00	446.00	2.50	Y
8/28/2004	TSS	12-Wet	Bear Creek - Rnd 4	18.00	19.00	5.41	Y
8/28/2004	Phosphorous	12-Wet	Buf @ West - Rnd 3	1.01	0.74	30.86	N
8/28/2004	TDS	12-Wet	Buf @ West - Rnd 3	384.00	389.00	1.29	Y
8/28/2004	TSS	12-Wet	Buf @ West - Rnd 3	108.00	102.00	5.71	Y
8/28/2004	Phosphorous	12-Wet	Langham Creek - Rnd 3	5.60	5.26	6.26	Y
8/28/2004	TDS	12-Wet	Langham Creek - Rnd 3	472.00	449.00	4.99	Y
8/28/2004	TSS	12-Wet	Langham Creek - Rnd 3	37.00	32.00	14.49	Y
8/28/2004	Phosphorous	12-Wet	Mason Creek - Rnd 5	2.74	3.01	9.39	Y
8/28/2004	TDS	12-Wet	Mason Creek - Rnd 5	251.00	247.00	1.61	Y
8/28/2004	TSS	12-Wet	Mason Creek - Rnd 5	134.00	141.00	5.09	Y

Notes:
Task corresponds to task # for Work Order 6
Values < detection limit were treated as half the detection limit
DQO = Data quality objective, it is met when RPD < 20
RPD = relative percent difference, calculated for bacteria by

RPD = Log (X1) - Log (X2)

Table 11.3 Field Sample Split Results - *E. coli*

Count	Date	Task	Sample ID	Result 1 (mg/L)	Result 2 (mg/L)	RPD	RPD < criteria?
1	6/15/2004	9	10495-139-I	9	<1	1.24	Y
2	6/30/2004	9	12795-001-D	10	5	0.28	Y
3	6/30/2004	9	12795-001-I	<1	<1	0.00	Y
4	7/12/2004	9	12516-001-D	<1	<1	0.00	Y
5	7/25/2004	12-Wet	Addicks Dis - Rnd 3	18600	18205	0.01	Y
6	7/25/2004	12-Wet	Buf @ West - Rnd 1	20	21	0.01	Y
7	7/25/2004	12-Wet	Dairy Ash - Rnd 3	29645	38800	0.12	Y
8	8/5/2004	9	10495-109-E	186	56	0.52	Y
9	8/9/2004	12-Dry	Barker Dis	83	109	0.12	Y
10	8/19/2004	12-Wet	Barker Dis - Rnd 5	1368	801	0.23	Y
11	8/19/2004	12-Wet	Bear Creek - Rnd 2	21050	15070	0.15	Y
15	8/19/2004	12-Wet	Bear Creek - Rnd 4	808	775	0.02	Y
			Precision criteria for samples 1-15 = 3.28*2.69/15=			***0.73***	
16	8/19/2004	12-Wet	Dairy Ash - Rnd 3	79325	104624	0.12	Y
17	8/27/2004	12-Dry	Barker Disch - A DUP	472	580	0.09	Y
18	8/28/2004	12-Wet	Addicks Pool - Rnd 3 - DUP	2103	2783	0.12	Y
19	8/28/2004	12-Wet	Bear Creek - A - Rnd 4 DUP	20525	31015	0.18	Y
20	8/28/2004	12-Dry	Bear Creek- DUP -A	1932	1932	0.00	Y
21	8/28/2004	12-Wet	Buf @ West - A - Rnd 3 DUP	317	305	0.02	Y
22	8/28/2004	12-Wet	Langham Creek - A - Rnd 3 DUP	2651	3177	0.08	Y
23	8/28/2004	12-Wet	Mason Creek - A - Rnd 5 DUP	43520	41330	0.02	Y

Table 11.4 Laboratory Sterility Check Results

Date	Sample ID	EC Result (MPN/dL)
6/14/2004	Sterility Check	0
6/15/2004	Sterility Check	0
6/21/2004	Sterility Check	0
6/22/2004	Sterility Check	0
6/29/2004	Sterility Check	0
6/30/2004	Sterility Check	0
7/1/2004	Sterility Check	0
7/2/2004	Sterility Check	0
7/3/2004	Sterility Check	0
7/4/2004	Sterility Check	0
7/5/2004	Sterility Check	0
7/6/2004	Sterility Check	0
7/6/2004	Sterility Check	0
7/7/2004	Sterility Check	0
7/9/2004	Sterility Check	0
7/12/2004	Sterility Check	0
7/12/2004	Sterility Check	0
7/13/2004	Sterility Check	0
7/15/2004	Sterility Check	0
7/19/2004	Sterility Check	0
7/20/2004	Sterility Check	0
7/21/2004	Sterility Check	0
7/22/2004	Sterility Check	0
7/24/2004	Sterility Check	0
7/25/2004	Sterility Check	0
7/25/2004	Sterility Check	0
7/25/2004	Sterility Check	0
8/5/2004	Sterility Check	0

Laboratory duplicates were also performed. The laboratory duplicates are different from field duplicates and splits in that laboratory duplicates are performed on each sample to document the variability associated with the IDEXX method. Although the IDEXX method is reliable, it is subject to interpretation to some extent. For example, one individual may consider a cell positive while another might consider it negative. Additionally, bacteria concentrations are well known to be highly variable and subject to culturability constraints. Based upon previous experience with this method, a high level of variability has been noted between duplicates.

Thus, each sample that was collected in the field was run in the laboratory with non-wet weather samples being run in triplicate and runoff samples being run in duplicate (due to the high number of samples being processed at one time). The results of the laboratory duplicates are presented in Table 11.5. When triplicates were run, the values in the table were the minimum and maximum EC concentration within the dilution that was readable. If two dilutions were readable, then the higher readable dilution was chosen for inclusion on the table. As the table shows, there are only two instances when the duplicates do not meet the precision criteria. These exceedances of the criterion were not considered to fail the criterion as bacteria data are inherently variable.

Table 11.5 Laboratory Duplicate Precision Results

Count	Date	Sample ID	E. COLI (MPN/100mL)					Accept?
			D1	D2	L1	L2	R_{logs}	
1	6/14/2004	12465-001-U	461.1	275.5	2.66	2.44	0.22	-
2	6/15/2004	10495-139-U	6131	5172	3.79	3.71	0.07	-
3	6/21/2004	10495-099-D	17850	13540	4.25	4.13	0.12	-
4	6/21/2004	10495-099-U	230	155.3	2.36	2.19	0.17	-
5	6/22/2004	11375-001-D	1178	1124	3.07	3.05	0.02	-
6	6/22/2004	11375-001-I	1317	1169	3.12	3.07	0.05	-
7	6/22/2004	11375-001-U	882	836	2.95	2.92	0.02	-
8	6/29/2004	12222-001-D	198.9	151.5	2.30	2.18	0.12	-
9	6/29/2004	12222-001-I	272.3	218.7	2.44	2.34	0.10	-
10	6/29/2004	12222-001-U	461.1	238.2	2.66	2.38	0.29	-
11	6/30/2004	12795-001-U	1145	771	3.06	2.89	0.17	-
12	7/12/2004	10495-109-D	238.2	166.4	2.38	2.22	0.16	Y
13	7/12/2004	10495-109-I	435.2	325.5	2.64	2.51	0.13	Y
14	7/12/2004	10495-109-U	344.8	201.4	2.54	2.30	0.23	Y
15	7/12/2004	12516-001-U	90.9	58.3	1.96	1.77	0.19	Y
		Precision criteria for first 15 = 3.28*2.23/15=					***0.45***	
16	7/12/2004	10495-109-D	238.2	166.4	2.38	2.22	0.16	Y
17	7/12/2004	10495-109-I	435.2	325.5	2.64	2.51	0.13	Y
18	7/12/2004	10495-109-U	344.8	201.4	2.54	2.30	0.23	Y
19	7/12/2004	12516-001-U	90.9	58.3	1.96	1.77	0.19	Y
20	7/13/2004	12834-001-D	547.5	410.6	2.74	2.61	0.12	Y
21	7/13/2004	12834-001-E	106.7	90.7	2.03	1.96	0.07	Y
22	7/13/2004	12834-001-I	613.1	547.5	2.79	2.74	0.05	Y
23	7/13/2004	12834-001-U	387.3	325.5	2.59	2.51	0.08	Y
24	7/24/2004	Addicks Dis	32550	22820	4.51	4.36	0.15	Y
25	7/24/2004	Barker Dis	141.4	124.6	2.15	2.10	0.05	Y
26	7/24/2004	Bear Creek	137.6	104.3	2.14	2.02	0.12	Y
27	7/24/2004	Dairy Ash	16070	13760	4.21	4.14	0.07	Y
28	7/24/2004	Langham Creek	18420	17850	4.27	4.25	0.01	Y
29	7/24/2004	S. Mayde Creek	547.5	325.5	2.74	2.51	0.23	Y
30	7/24/2004	Turkey Creek	4611	4611	3.66	3.66	0.00	Y
31	7/25/2004	Addicks Dis - Rnd 1	1658	988	3.22	2.99	0.22	Y
32	7/25/2004	Addicks Dis - Rnd 2	17850	16160	4.25	4.21	0.04	Y
33	7/25/2004	Addicks Dis - Rnd 3	19350	17850	4.29	4.25	0.04	Y
34	7/25/2004	Addicks Dis - Rnd 3-DUP	19180	17230	4.28	4.24	0.05	Y
35	7/25/2004	B. Clidne Ditch - Rnd 1	24890	15150	4.40	4.18	0.22	Y
36	7/25/2004	Barker Dis - Rnd 2	36540	24810	4.56	4.39	0.17	Y
37	7/25/2004	Barker Dis - Rnd 3	34480	26130	4.54	4.42	0.12	Y
38	7/25/2004	Bear Creek - Rnd 1	15000	10710	4.18	4.03	0.15	Y
39	7/25/2004	Bear Creek - Rnd 3	111985	75550	5.05	4.88	0.17	Y
40	7/25/2004	Buf @ West - Rnd 1	18.5	13.2	1.27	1.12	0.15	Y
41	7/25/2004	Buf @ West - Rnd 1-DUP	19.7	13.2	1.29	1.12	0.17	Y

Count	Date	Sample ID	E. COLI (MPN/100mL)					Accept?
			D1	D2	L1	L2	R_{logs}	
42	7/25/2004	Buf @ West - Rnd 2	37.3	34.5	1.57	1.54	0.03	Y
43	7/25/2004	Dairy Ash - Rnd 1	104624	77010	5.02	4.89	0.13	Y
44	7/25/2004	Dairy Ash - Rnd 2	54750	51720	4.74	4.71	0.02	Y
45	7/25/2004	Dairy Ash - Rnd 3	34480	24810	4.54	4.39	0.14	Y
46	7/25/2004	Dairy Ash - Rnd 3-DUP	41060	36540	4.61	4.56	0.05	Y
47	7/25/2004	Langham Creek - Rnd 1	17850	12360	4.25	4.09	0.16	Y
48	7/25/2004	Langham Creek - Rnd 2	29090	22470	4.46	4.35	0.11	Y
49	7/25/2004	Langham Creek - Rnd 3	4840	4190	3.68	3.62	0.06	Y
50	7/25/2004	S. Mayde Creek - Rnd 2	46110	32550	4.66	4.51	0.15	Y
51	7/25/2004	S. Mayde Creek - Rnd 3	54750	48840	4.74	4.69	0.05	Y
52	7/25/2004	Turkey Creek - Rnd 1	4884	4106	3.69	3.61	0.08	Y
53	7/25/2004	Turkey Creek - Rnd 2	1146	1093	3.06	3.04	0.02	Y
54	7/25/2004	Turkey Creek - Rnd 3	19560	15150	4.29	4.18	0.11	Y
55	8/5/2004	10495-109-E	307.6	63.8	2.49	1.80	0.68	
56	8/9/2004	Addicks Dis	126.7	84.2	2.10	1.93	0.18	Y
57	8/9/2004	Barker Dis	119.8	98.7	2.08	1.99	0.08	Y
58	8/9/2004	Barker Dis - DUP	85	80.1	1.93	1.90	0.03	Y
59	8/9/2004	Bear Creek	591	422	2.77	2.63	0.15	Y
60	8/9/2004	Langham Creek	185	167.4	2.27	2.22	0.04	Y
61	8/9/2004	S. Mayde Creek	235.9	178.5	2.37	2.25	0.12	Y
62	8/13/2004	10584-001-D	882	496	2.95	2.70	0.25	Y
63	8/13/2004	10584-001-E	79.4	61.3	1.90	1.79	0.11	Y
64	8/13/2004	10584-001-U	1112	691	3.05	2.84	0.21	Y
65	8/19/2004	Addicks Dis - Rnd 6	2382	2359	3.38	3.37	0.00	Y
66	8/19/2004	Addicks Dis - Rnd 1	140.1	125.9	2.15	2.10	0.05	Y
67	8/19/2004	Addicks Dis - Rnd 2	547.5	461.1	2.74	2.66	0.07	Y
68	8/19/2004	Addicks Dis - Rnd 3	6131	4884	3.79	3.69	0.10	Y
69	8/19/2004	Addicks Dis - Rnd 4	3448	2755	3.54	3.44	0.10	Y
70	8/19/2004	Addicks Dis - Rnd 5	3255	2909	3.51	3.46	0.05	Y
71	8/19/2004	Barker Dis - Rnd 5 - DUP	836	766	2.92	2.88	0.04	Y
72	8/19/2004	Barker Dis - Rnd 1	75.4	63	1.88	1.80	0.08	Y
73	8/19/2004	Barker Dis - Rnd 2	3448	3255	3.54	3.51	0.03	Y
74	8/19/2004	Barker Dis - Rnd 3	1169	754	3.07	2.88	0.19	Y
75	8/19/2004	Barker Dis - Rnd 4	1187	1145	3.07	3.06	0.02	Y
		Precision criteria for samples 61-75 = 3.28*1.41/15=					***0.31***	
100	8/19/2004	Barker Dis - Rnd 5	1500	1236	3.18	3.09	0.08	Y
101	8/19/2004	Bear Creek - Rnd 1	142.1	127.4	2.15	2.11	0.05	Y
102	8/19/2004	Bear Creek - Rnd 2	27550	14550	4.44	4.16	0.28	Y
103	8/19/2004	Bear Creek - Rnd 2 - DUP	17230	12910	4.24	4.11	0.13	Y
104	8/19/2004	Bear Creek - Rnd 3	4352	3130	3.64	3.50	0.14	Y
105	8/19/2004	Bear Creek - Rnd 4	836	780	2.92	2.89	0.03	Y
106	8/19/2004	Bear Creek - Rnd 4 - DUP	833	717	2.92	2.86	0.07	Y
107	8/19/2004	Bear Creek - Rnd 5	46110	27550	4.66	4.44	0.22	Y
108	8/19/2004	Buf @ West - Rnd 2	547.5	461.1	2.74	2.66	0.07	Y

Count	Date	Sample ID	E. COLI (MPN/100mL)					Accept?
			D1	D2	L1	L2	R_{logs}	
109	8/19/2004	Buf @ West - Rnd 3	195.6	161.6	2.29	2.21	0.08	Y
110	8/19/2004	Buf @ West - Rnd 4	204.6	166.4	2.31	2.22	0.09	Y
111	8/19/2004	Dairy Ash - Rnd 1	547.5	387.3	2.74	2.59	0.15	Y
112	8/19/2004	Dairy Ash - Rnd 3	81640	77010	4.91	4.89	0.03	Y
113	8/19/2004	Dairy Ash - Rnd 4	111985	104624	5.05	5.02	0.03	Y
114	8/19/2004	Dairy Ash - Rnd 5	20630	19040	4.31	4.28	0.03	Y
115	8/19/2004	Langham Creek - Rnd 1	172.3	137.6	2.24	2.14	0.10	Y
116	8/19/2004	Langham Creek - Rnd 2	1287	1081	3.11	3.03	0.08	Y
117	8/19/2004	Langham Creek - Rnd 3	2382	2014	3.38	3.30	0.07	Y
118	8/19/2004	Langham Creek - Rnd 4	3609	2359	3.56	3.37	0.18	Y
119	8/19/2004	Langham Creek - Rnd 5	1904	1607	3.28	3.21	0.07	Y
120	8/19/2004	Mason Creek - Rnd 1	29090	22470	4.46	4.35	0.11	Y
121	8/19/2004	S. Mayde Creek - Rnd 1	1187	1145	3.07	3.06	0.02	Y
122	8/19/2004	S. Mayde Creek - Rnd 1	1607	1223	3.21	3.09	0.12	Y
123	8/19/2004	S. Mayde Creek - Rnd 2	1553	1354	3.19	3.13	0.06	Y
124	8/19/2004	S. Mayde Creek - Rnd 3	5475	4611	3.74	3.66	0.07	Y
125	8/19/2004	S. Mayde Creek - Rnd 4	3255	2755	3.51	3.44	0.07	Y
126	8/19/2004	Turkey Creek - Rnd 6	10190	9880	4.01	3.99	0.01	Y
127	8/19/2004	Turkey Creek - Rnd 1	1565	1467	3.19	3.17	0.03	Y
128	8/19/2004	Turkey Creek - Rnd 2	32550	23820	4.51	4.38	0.14	Y
129	8/19/2004	Turkey Creek - Rnd 4	2909	2481	3.46	3.39	0.07	Y
130	8/19/2004	Turkey Creek - Rnd 5	10860	9590	4.04	3.98	0.05	Y
131	8/27/2004	Addicks Discharge	613.1	579.4	2.79	2.76	0.02	Y
132	8/27/2004	Barker Dis	613.1	547.5	2.79	2.74	0.05	Y
133	8/27/2004	Barker Disch DUP	488.4	435.2	2.69	2.64	0.05	Y
134	8/27/2004	Bear Creek	2247	1616	3.35	3.21	0.14	Y
135	8/27/2004	Bear Creek- DUP	2014	1850	3.30	3.27	0.04	Y
136	8/27/2004	Buf @ West	435.2	307.6	2.64	2.49	0.15	Y
137	8/27/2004	Langham Creek	950	882	2.98	2.95	0.03	Y
138	8/27/2004	Mason Creek	2142	1624	3.33	3.21	0.12	Y
139	8/27/2004	S. Mayde Creek	228.2	161.6	2.36	2.21	0.15	Y
140	8/27/2004	Turkey Creek	117.8	85	2.07	1.93	0.14	Y
141	8/28/2004	Addicks Dis - Rnd 1	1223	1010	3.09	3.00	0.08	Y
142	8/28/2004	Addicks Pool - Rnd 2	2282	2143	3.36	3.33	0.03	Y
143	8/28/2004	Addicks Pool - Rnd 3	2481	1725	3.39	3.24	0.16	Y
144	8/28/2004	Addicks Pool - Rnd 3 - DUP	3076	2489	3.49	3.40	0.09	Y
145	8/28/2004	Addicks Pool - Rnd 4	1725	1565	3.24	3.19	0.04	Y
146	8/28/2004	Addicks Pool - Rnd 5	34480	26020	4.54	4.42	0.12	Y
147	8/28/2004	Barker Dis - Rnd 2	2723	1789	3.44	3.25	0.18	Y
148	8/28/2004	Barker Dis - Rnd 3	3282	3255	3.52	3.51	0.00	Y
149	8/28/2004	Barker Dis - Rnd 4	2143	1607	3.33	3.21	0.13	Y
150	8/28/2004	Barker Dis - Rnd 5	2282	1678	3.36	3.22	0.13	Y
151	8/28/2004	Bear Creek - Rnd 2	2602	1616	3.42	3.21	0.21	Y
152	8/28/2004	Bear Creek - Rnd 3	2481	2035	3.39	3.31	0.09	Y
153	8/28/2004	Bear Creek - Rnd 4	21870	19180	4.34	4.28	0.06	Y

Count	Date	Sample ID	E. COLI (MPN/100mL)					Accept?
			D1	D2	L1	L2	R_{logs}	
154	8/28/2004	Bear Creek - Rnd 4 DUP	34480	27550	4.54	4.44	0.10	Y
155	8/28/2004	Buf @ West - Rnd 1	290.9	272.3	2.46	2.44	0.03	Y
156	8/28/2004	Buf @ West - Rnd 2	547.5	461.1	2.74	2.66	0.07	Y
157	8/28/2004	Buf @ West - Rnd 3	325.5	307.6	2.51	2.49	0.02	Y
158	8/28/2004	Buf @ West - Rnd 3 DUP	325.5	285.1	2.51	2.45	0.06	Y
159	8/28/2004	Buf @ West - Rnd 4	416	410.6	2.62	2.61	0.01	Y
160	8/28/2004	Buf @ West - Rnd 5	285.1	248.9	2.45	2.40	0.06	Y
161	8/28/2004	Dairy Ash - Rnd 1	32550	29090	4.51	4.46	0.05	Y
162	8/28/2004	Dairy Ash - Rnd 3	30760	17230	4.49	4.24	0.25	Y
163	8/28/2004	Dairy Ash - Rnd 4	86640	77010	4.94	4.89	0.05	Y
164	8/28/2004	Dairy Ash - Rnd 5	34480	26020	4.54	4.42	0.12	Y
165	8/28/2004	Langham Creek - Rnd 2	3448	1918	3.54	3.28	0.25	Y
166	8/28/2004	Langham Creek - Rnd 3	3255	2046	3.51	3.31	0.20	Y
167	8/28/2004	Langham Creek - Rnd 3 DUP	2098	1850	3.32	3.27	0.05	Y
168	8/28/2004	Langham Creek - Rnd 4	3448	1918	3.54	3.28	0.25	Y
169	8/28/2004	Mason Creek - Rnd 5	43520	43520	4.64	4.64	0.00	Y
170	8/28/2004	Mason Creek - Rnd 5 DUP	41600	41060	4.62	4.61	0.01	Y
171	8/28/2004	S. Mayde Creek - Rnd 1	2602	1223	3.42	3.09	0.33	
172	8/28/2004	S. Mayde Creek - Rnd 2	2142	1374	3.33	3.14	0.19	Y
173	8/28/2004	S. Mayde Creek - Rnd 3	1376	1259	3.14	3.10	0.04	Y
174	8/28/2004	S. Mayde Creek - Rnd 4	1296	1187	3.11	3.07	0.04	Y
175	8/28/2004	Turkey Creek - Rnd 1	5475	4884	3.74	3.69	0.05	Y
176	8/28/2004	Turkey Creek - Rnd 2	12740	9070	4.11	3.96	0.15	Y
177	8/28/2004	Turkey Creek - Rnd 3	14400	10810	4.16	4.03	0.12	Y

Notes:

CHAPTER 12

CONCLUSIONS AND FUTURE WORK

Buffalo and Whiteoak Bayous are considered to be water quality impaired due to high levels of fecal indicator bacteria. The work completed in Work Order 6 provided insight into the causes and potential mitigation of the sources. Work Order (WO6) explored additional potential sources of bacteria and their impacts on water quality. Additionally, WO6 evaluated the potential impacts of water withdrawals on water quality in the 2 bayous. The conclusions will be discussed below in the order of the chapters that were presented in this document. Future work will be presented subsequent to the conclusions.

Assessment of Biosolids Releases

Two methods, the biosolids generating factor and the mass balance approach, were used to estimate the generation of biosolids by WWTP in the Buffalo and Whiteoak Bayou watersheds. Most estimates were relatively close to the amount of biosolids reportedly disposed of by the plants. Some estimates, however, over- or under-estimated the reported biosolids by as much as 25%. These estimates were found to have a high level of uncertainty associated with them and therefore could not be used solely to determine if a plant was mismanaging their sludge. These estimates, however, could be used as an indicator of potential problems requiring a detailed evaluation. A somewhat detailed evaluation of plant operation and maintenance would be necessary to conclude with certainty that a specific plant was not properly manage biosolids.

Water Withdrawals and Diversions

Permit requests from the City of Houston currently under review by TCEQ involve reuse of WWTP effluent and also request water rights to unappropriated water in both Buffalo and Whiteoak Bayous. The effects of these permits on bayou flows is significant, as the majority of the low flow in the bayous is due to WWTP discharges. If the requested water reuse and water withdrawals were in full effect, it is possible that the bayous could be dry during periods of extended dry weather. Bacteria concentrations will also be affected by the reuse and withdrawals. The consequences are diverse, since reuse and withdrawals would affect both sediment-associated fecal indicator bacteria as well as planktonic, or free-living, bacteria.

Sediment Contributions

Tests were run to assess the impact of sediment on bacteria concentrations in the bayou as well as to investigate settling properties of bayou sediments. The bacteria concentrations gathered

from bayou sediments could not be related to the presence of WWTPs on the reach, although it is noted that only limited data were gathered. Additionally, settling experiments indicated that TSS concentrations in quiescent conditions would reduce to very low levels within 24 hours, while EC concentrations mostly exhibited initial increases in concentrations and had very low die-off rates after the initial increase. The settling experiments also indicated that bacteria are not strongly associated with the larger sediment that settles rapidly, but rather with smaller particles that settle more slowly.

Levels of EC in Addicks and Barker Reservoirs

The magnitude of EC loading from the Addicks and Barker reservoirs was assessed through a series of field sampling activities during three wet and three dry weather events. Dry weather concentrations of EC were generally found to be lower than wet weather concentrations, although they still exceeded the long-term geometric mean water quality standard 72% of the time (based upon the 3 dry weather events). All wet weather samples, except for those collected at Buffalo Bayou at Westheimer, were above the water quality standard. Differences between wet and dry weather could not be statistically supported, but with more data, it is certain that they would be.

The post-impoundment reservoir sampling conducted following the June 2004 rains demonstrated that the reservoirs do have a drastic effect on water quality. During the month of water impoundment, EC and TSS concentrations were attenuated, with EC concentrations falling well below the water quality standard. Although the concentrations from the reservoir discharges were very low, the concentrations downstream at Dairy Ashford often exceeded the water quality standard. This may indicate that elevated concentrations at Dairy Ashford (and other locations downstream) are influenced by other factors in addition to the reservoir discharges.

Quantification of Bacteria Loads from Overflows and Bypasses

The potential impact of inputs from the sanitary sewage system (including consideration of untreated sewage bypasses at treatment facilities, releases of untreated sewage from the collection

system during dry weather and releases of untreated sewage from the collection system during wet weather) was assessed through the use of data analysis and limited field data collection. Untreated sewage bypasses at treatment facilities were closed or removed prior to 1997 and thus these types of bypasses cannot physically occur. Releases of untreated sewage from the collection system during dry weather was another potential input examined through the use of databases provided by the City of Houston and field sampling of dry weather WWTP influent prior to treatment. The results of this analysis indicate that overflows could impact water quality, but the impacts are difficult to quantify as significant variability is associated with this source. Finally, wet weather facilities (WWF) were examined. There were no WWF found in the Buffalo and Whiteoak Bayou watersheds. Furthermore, it was not possible to prove that discharges from these facilities in other watersheds during wet weather impacted water quality downstream.

<u>Assessment of E. coli downstream of Wastewater Treatment Plant Outfalls</u>

The impact of WWTPs on bacteria concentrations and water quality in general was assessed through field sampling conducted at the effluent pipe as well as upstream and downstream of the plant. A total of 10 plants were sampled. No obvious trends could be discerned from the collected data. Forty percent of the time, the effluent EC concentrations were elevated above 50 MPN/dL and once the effluent exceeded the in-stream instantaneous water quality standard of 394 MPN/dL. Although effluent does not have a numeric standard for EC, bacteria concentrations at these levels suggest that chlorination is not effectively inactivating all the bacteria. No clear impacts from the elevated concentrations could be discerned downstream of the plant.

<u>Bacteria Source Tracking</u>

Fecal samples from humans, horses, cows, dogs, bats, and birds were from the Houston area during two sampling events. EC isolates were obtained and both ARA and PFGE were conducted on the isolates to develop a source database. The database was statistically analyzed and the rates of correct classification for human versus non-human sources was 89%, which is comparable to studies conducted in other parts of the United States. Four unknown samples were also collected and processed to isolate EC.

HPSF Model Expansion

Time-varying flows and concentrations were developed through the use of data provided by the City of Houston for six WWTPs and EC data collected during Work Order #2. A set of conversion factors were developed to convert self-reported monthly flows into time-varying flow. The time-varying flows and concentrations were input into the HSPF model and used for calibration.

The HSPF model was expanded to included the subwatersheds above Barker and Addicks Reservoir. The inclusion of these watersheds allows for the explicit modeling of the reservoirs and their effects, although this introduces some error since the model cannot replicate the exact operation of the reservoirs. Buffalo and Whiteoak Bayous were re-calibrated and validated using data from January 1, 2001 through September 30, 2004, which allows for the comparison of model output to true EC concentrations. Model simulations were found to be adequate, but the models are continuously refined to improve their performance in matching the measured data.

Quality Assurance Project Plan (QAPP) and Quality Control

The QAPP was followed in all field sampling and laboratory analysis. Quality control analysis conducted on the field and laboratory data suggest that all the data collected under the QAPP were acceptable for reporting.

Future Work and Recommendations

Based upon these findings, a Work Plan was developed and Work Order #8 has the following tasks that will be completed between September, 2004 and August 2005. These task are as follows:

1. Administer the project;
2. Participate in the stakeholder process;
3. Amend the approved quality assurance project plan (QAPP) for additional data collection;
4. Complete assessment of the impact of possible biosolid releases on bacteria levels;
5. Complete investigation of the levels from Addicks and Barker Reservoirs;
6. Complete assessment of E. coli levels downstream of WWTP outfalls;
7. Complete assessment of sediment contributions;
8. Complete investigations of bacteria loads from overflows and bypasses;
9. Integrate gathered data into the HPSF TMDL model;
10. Expand and refine the existing HSPF indicator bacteria model to focus more on the low and very low flow conditions;
11. Complete bacteria source tracking analyses;
12. Refine load allocation scenarios; and
13. Investigate and develop best management practice strategies for bacteria load reduction.

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APPENDIX A

SLIDES FROM STAKEHOLDER MEETINGS

Slides from Stakeholder Meeting

October 15, 2003

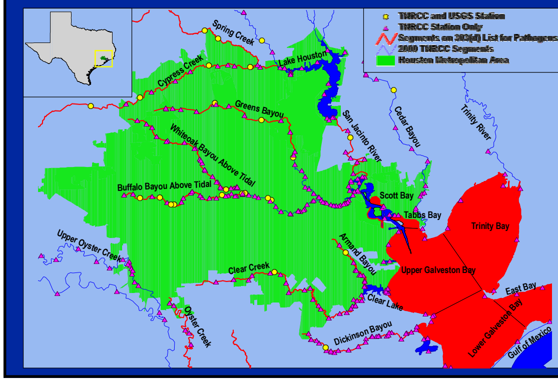
Modeling and Allocation Development for an Urban Indicator Bacteria TMDL

Tina Petersen, Hanadi S. Rifai and Monica Suarez, University of Houston

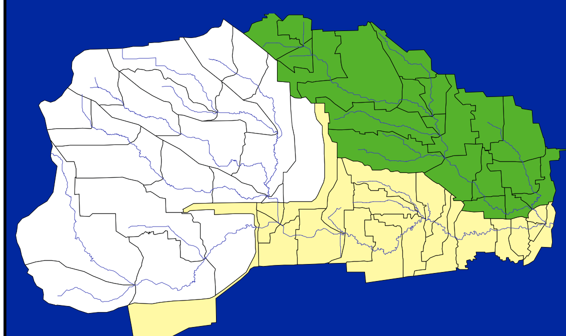
Paul Jensen and Yu-Chun Su, PBS&J

Ronald Stein, TCEQ

Houston Area Pathogen Impairments



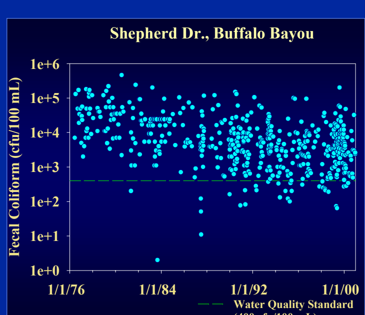
Buffalo and Whiteoak Bayous

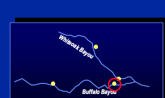


Texas Freshwater Bacteria Standards

E. coli	Geometric Mean	126 MPN/dL
	Not-to-Exceed	394 MPN/dL
Fecal coliform	Geometric Mean	200 cfu/dL
	Not-to-Exceed	400 cfu/dL

Historical Water Quality Data





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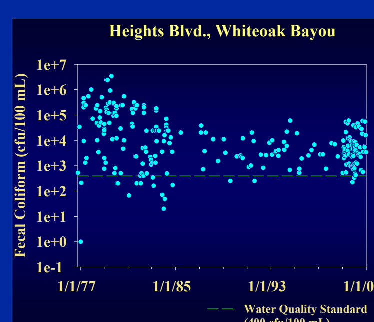
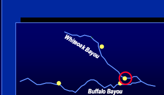
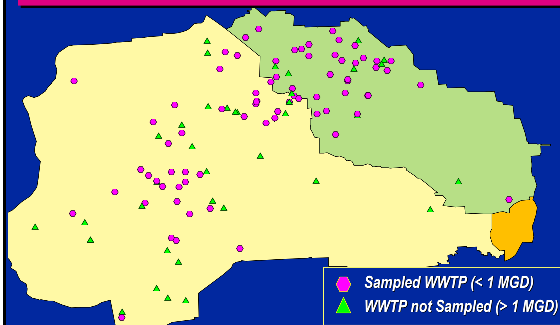




Potential Sources of EC in Buffalo and Whiteoak Bayous

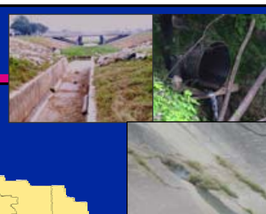
- Inadequate/Incomplete disinfection from WWTP effluent
- Failed septic systems
- Unpermitted discharges to storm sewers
- NPS stemming from wildlife in the watershed
- Bacteria from upstream sources (Buffalo Bayou Only)
- Urban NPS
- Stream sediment

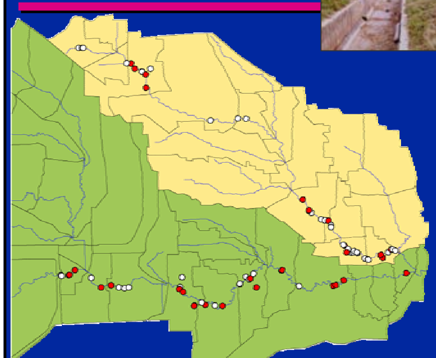
WWTP Sampling



n73; 8am and 10am Sampling

DWSS Sampling

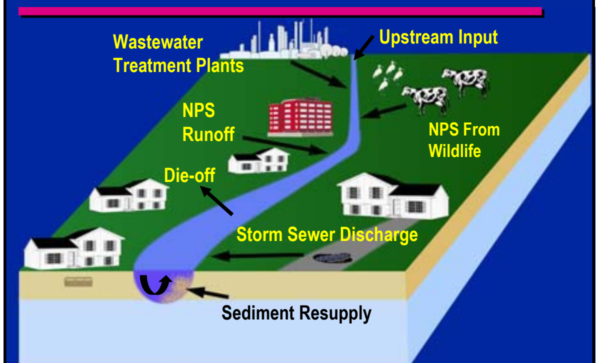




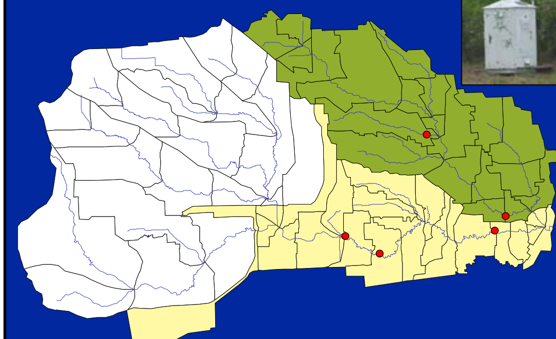
E. coli load for WWTP and Storm Sewers

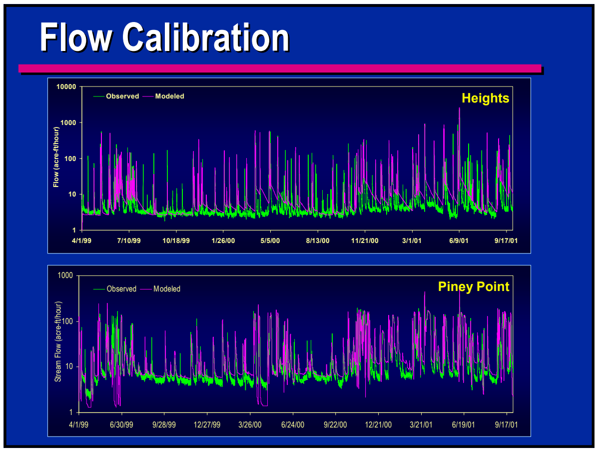
	WWTP Load (MPN/yr)	Storm Sewer Load (MPN/yr)
Buffalo Bayou	1.82E+12	7.89E+13
Whiteoak Bayou	5.83E+14	7.24E+13
Total	5.85E+14	1.51E+14

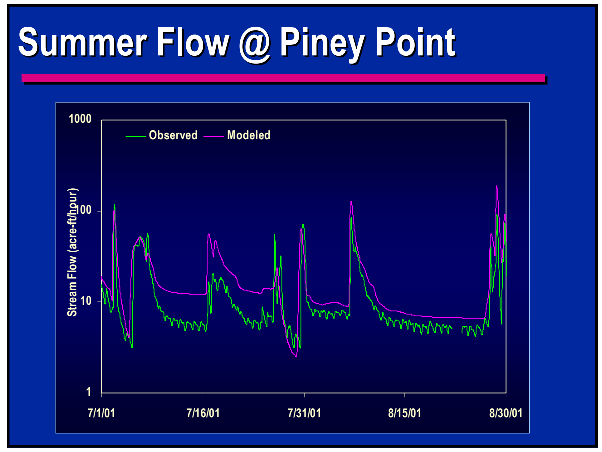
HSPF Conceptual Model

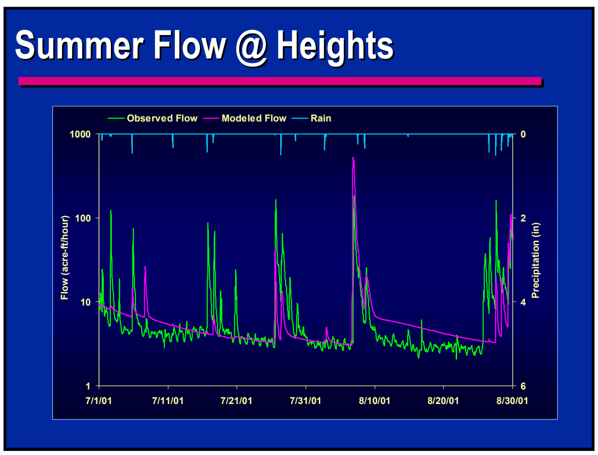


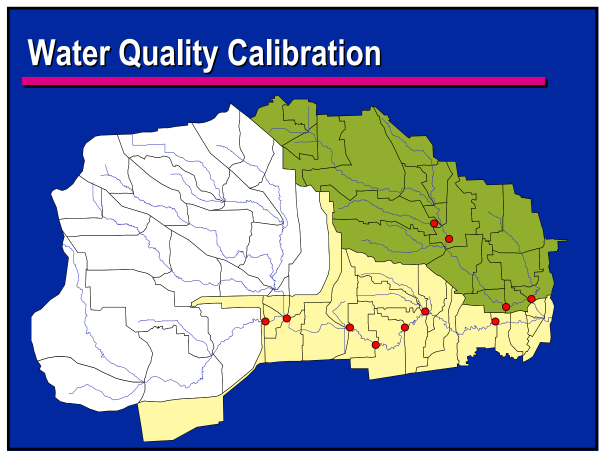
Flow Calibration

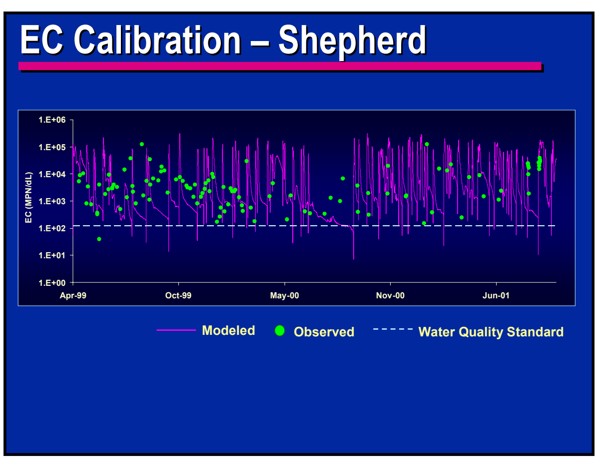


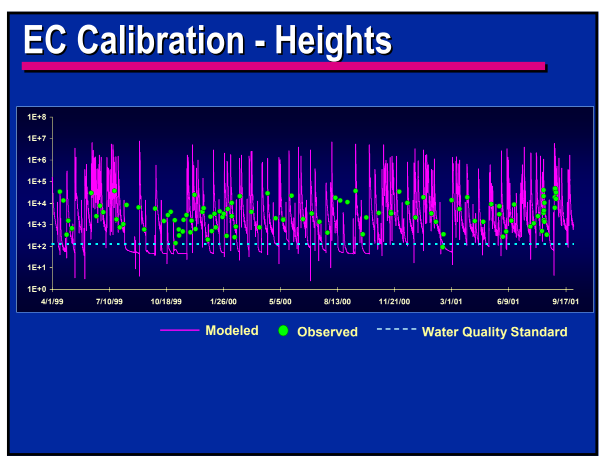

Flow Calibration
Heights
Observed
Modeled
Flow (acre-ft/hour)
Piney Point
Stream Flow (acre-ft/hour)


Summer Flow @ Piney Point
Observed
Modeled
Stream Flow (acre-ft/hour)
7/1/01
7/16/01
7/31/01
8/15/01
8/30/01

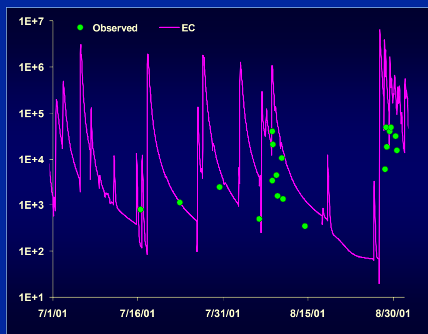

Summer Flow @ Heights
Observed Flow
Modeled Flow
Rain
Flow (acre-ft/hour)
Precipitation (in)
7/1/01
7/11/01
7/21/01
7/31/01
8/10/01
8/20/01
8/30/01


Water Quality Calibration

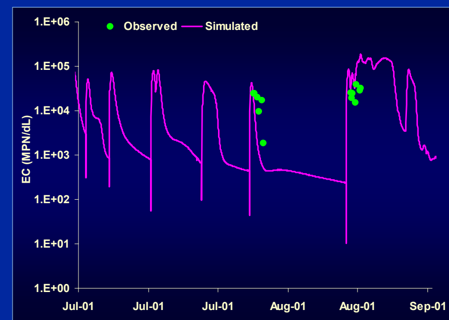

EC Calibration – Shepherd
EC (MPN/dL)
Apr-99
Oct-99
May-00
Nov-00
Jun-01
Modeled
Observed
Water Quality Standard


EC Calibration - Heights
Modeled
Observed
Water Quality Standard

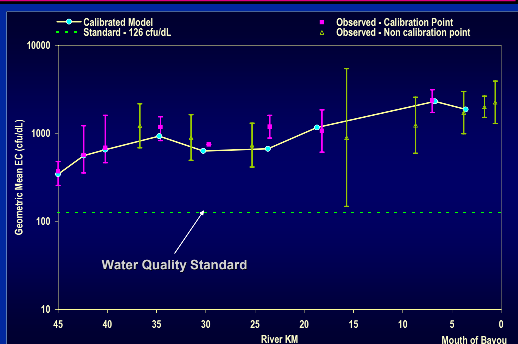
Summer EC @ Heights



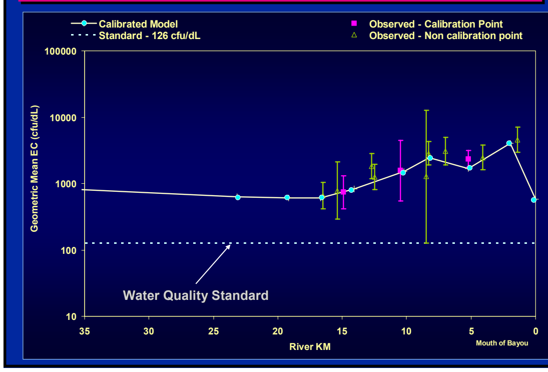
Summer EC @ Buffalo Bayou



Buffalo Bayou – Model Results



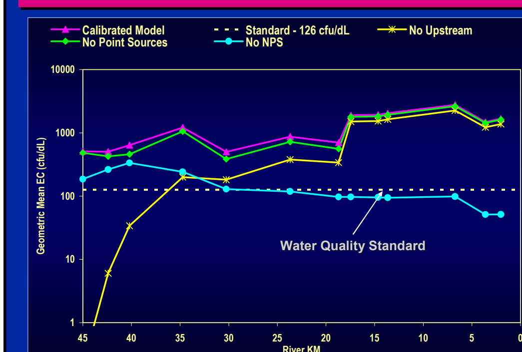
Whiteoak Bayou – Model Results

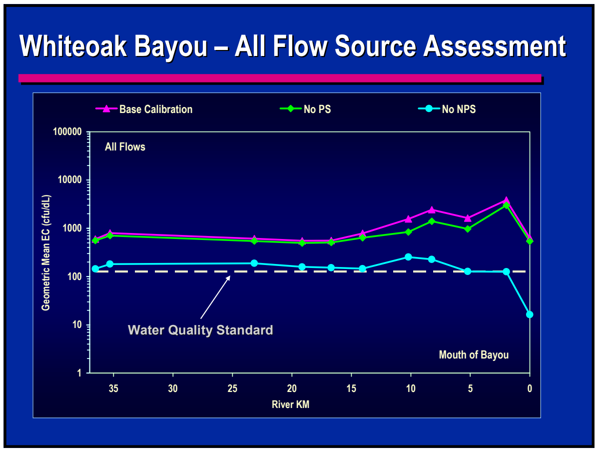


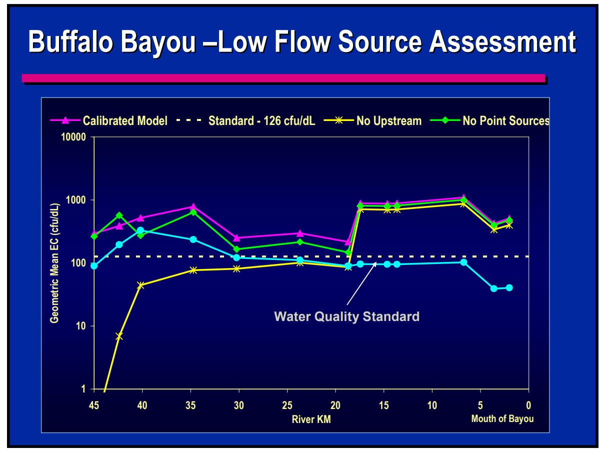
Source Assessment and Allocations

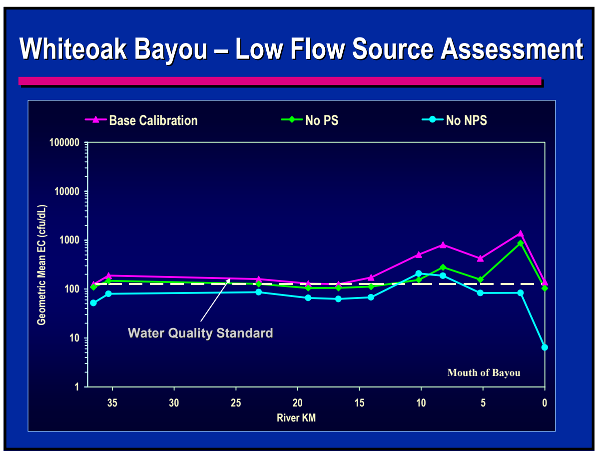
- Eliminate Unpermitted Stormwater EC Discharges
- Eliminate Wastewater Treatment Plant EC Discharges
- Eliminate Wildlife NPS Accumulation of EC
- Eliminate Upstream EC Inflow (Buffalo Bayou)

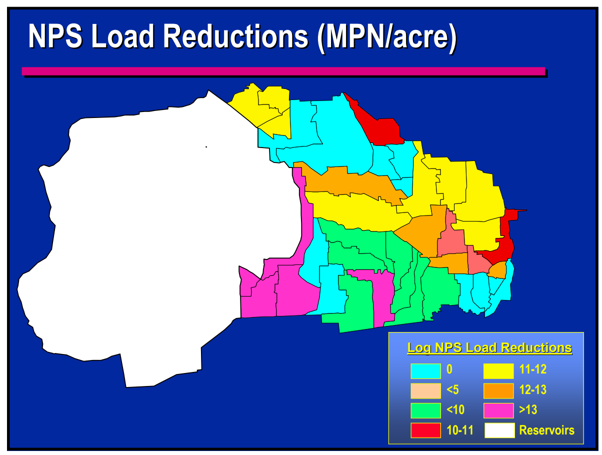
Buffalo Bayou –All Flow Source Assessment









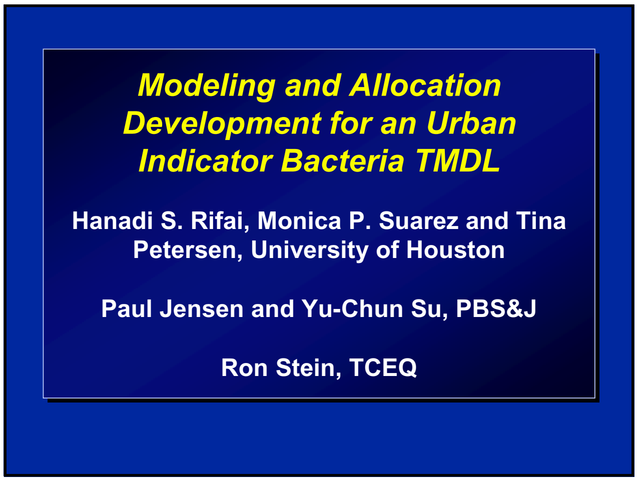


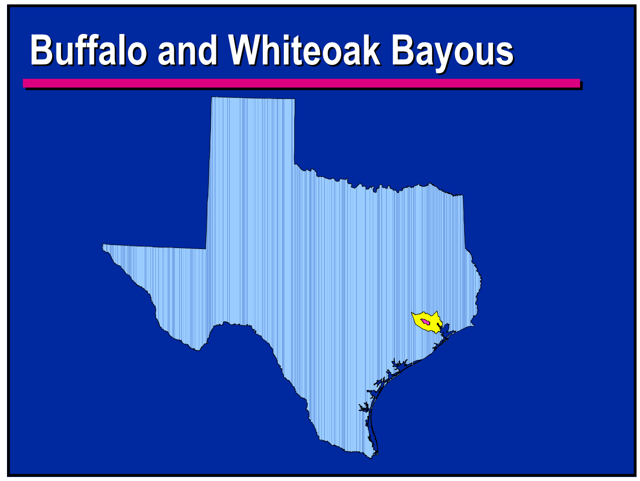
Conclusions

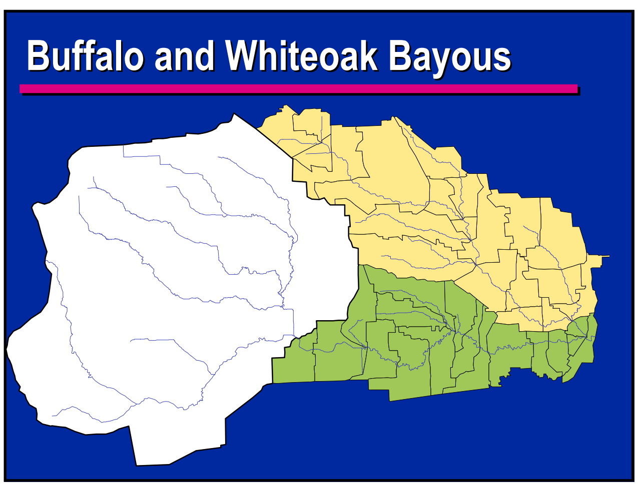
- Historically, EC concentrations in the bayous have been high
- NPS and Upstream Inputs (on Buffalo Bayou) are the most significant sources of bacteria
- NPS required reductions were found to be up to 10^{13} MPN/acre
- BMPs cannot achieve these reductions, so other strategies are being examined

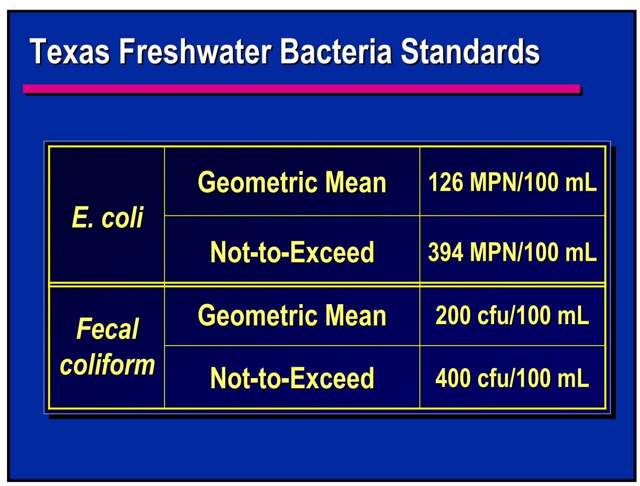
Slides from Stakeholder Meeting

January 28, 2004 and May 18, 2004

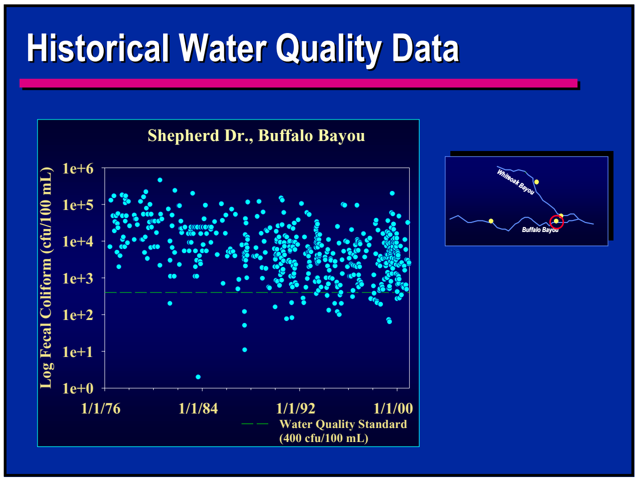


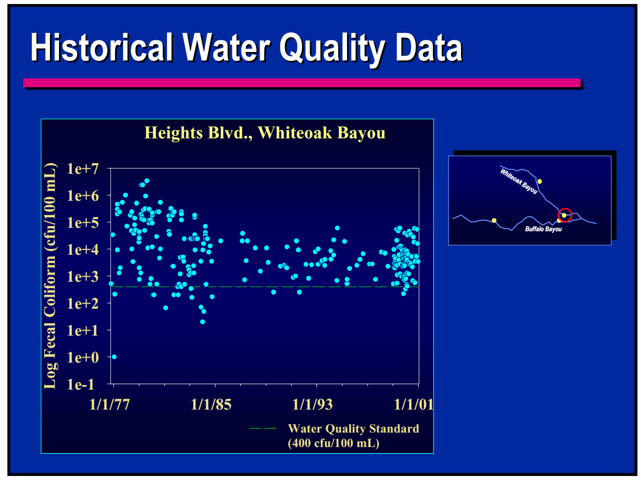


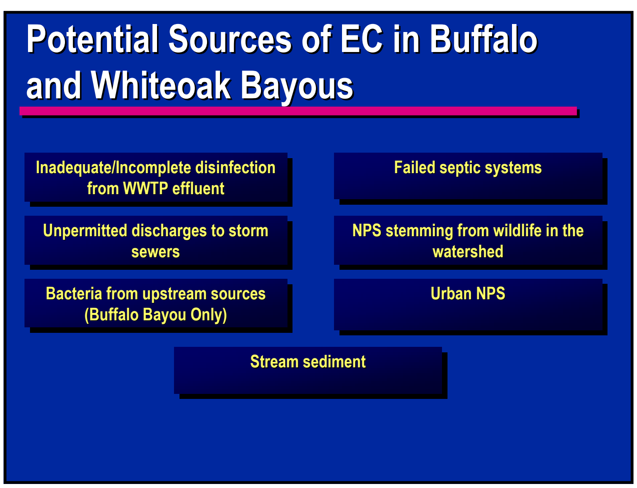


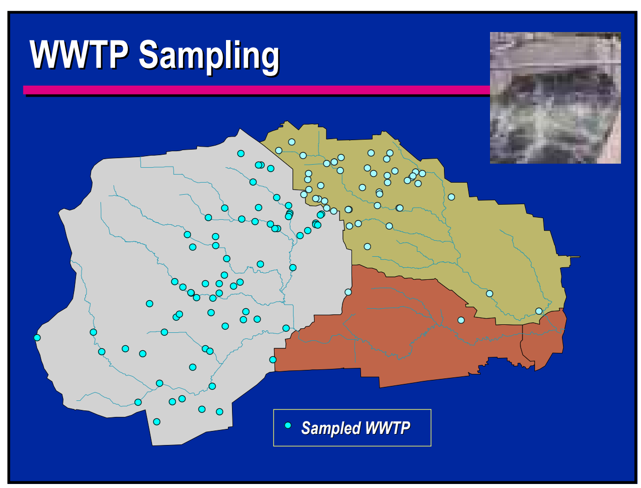


E. coli	Geometric Mean	126 MPN/100 mL
	Not-to-Exceed	394 MPN/100 mL
Fecal coliform	Geometric Mean	200 cfu/100 mL
	Not-to-Exceed	400 cfu/100 mL

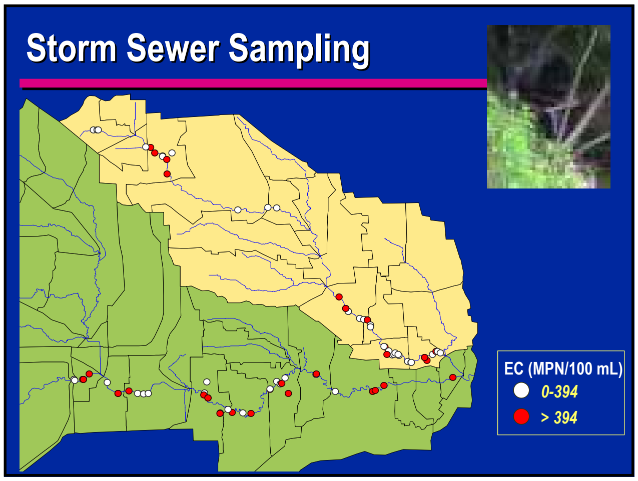

Historical Water Quality Data
Shepherd Dr., Buffalo Bayou
Log Fecal Coliform (cfu/100 mL)
1e+6
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1/1/76
1/1/84
1/1/92
1/1/00
Water Quality Standard
(400 cfu/100 mL)


Historical Water Quality Data
Heights Blvd., Whiteoak Bayou
Log Fecal Coliform (cfu/100 mL)
1e+7
1e+6
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
1/1/77
1/1/85
1/1/93
1/1/01
Water Quality Standard
(400 cfu/100 mL)


Potential Sources of EC in Buffalo and Whiteoak Bayous
Inadequate/Incomplete disinfection from WWTP effluent
Failed septic systems
Unpermitted discharges to storm sewers
NPS stemming from wildlife in the watershed
Bacteria from upstream sources (Buffalo Bayou Only)
Urban NPS
Stream sediment


WWTP Sampling
Sampled WWTP

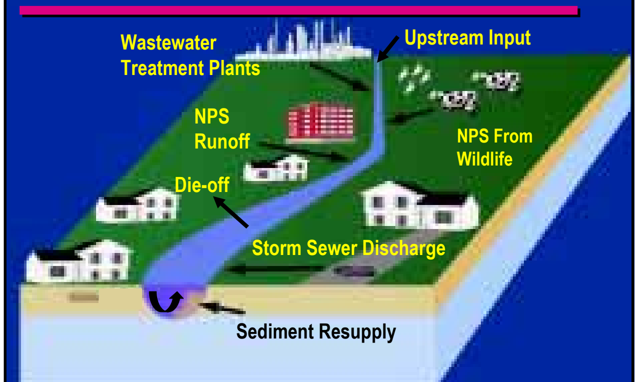
Storm Sewer Sampling



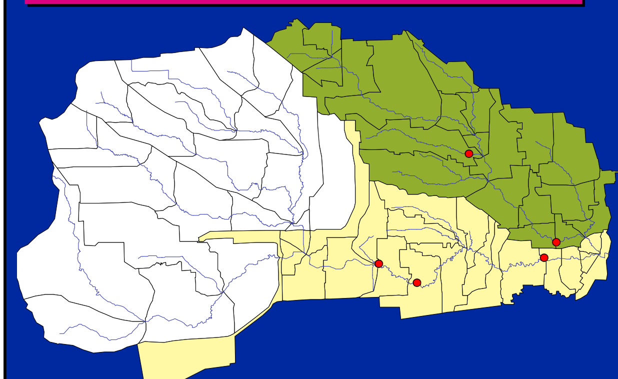
E. coli load for WWTP and Storm Sewers

	WWTP Load (MPN/yr)	Storm Sewer Load (MPN/yr)
Buffalo Bayou	1.82E+12	7.89E+13
Whiteoak Bayou	5.83E+14	7.24E+13
Total	5.85E+14	1.51E+14

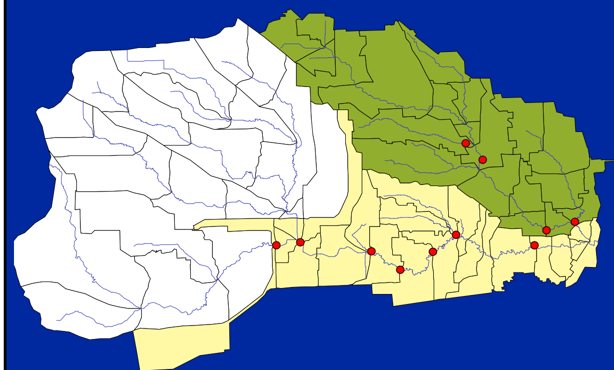
Conceptual Model



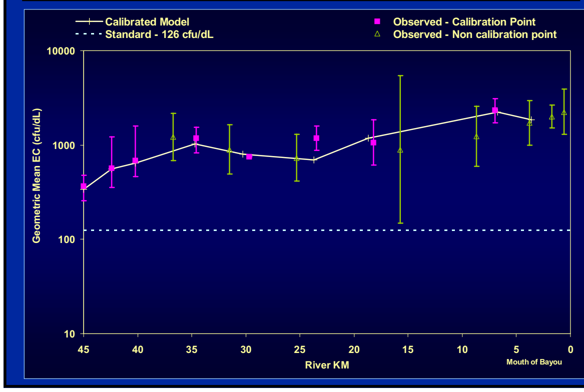
Hydrology Calibration Sites



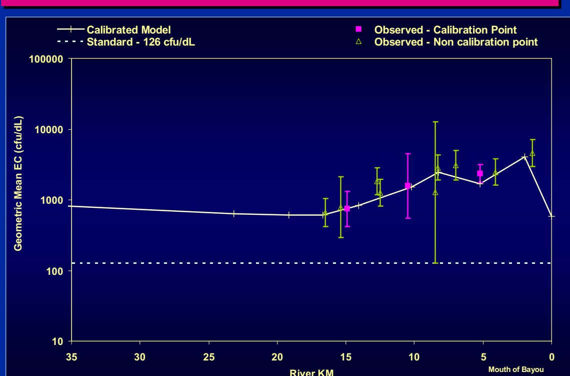
Water Quality Calibration Sites



Buffalo Bayou – Model Results

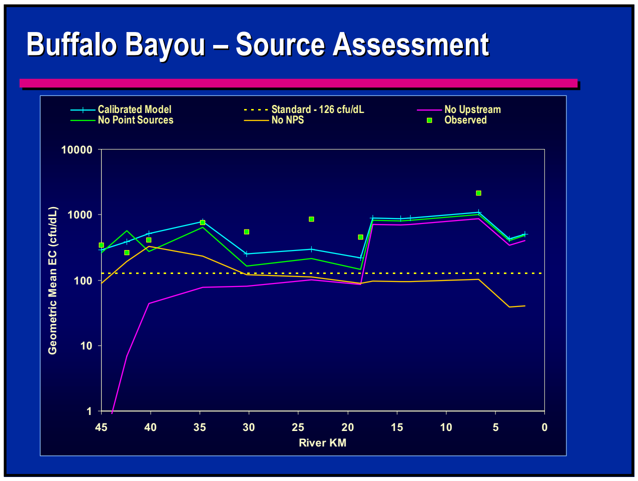


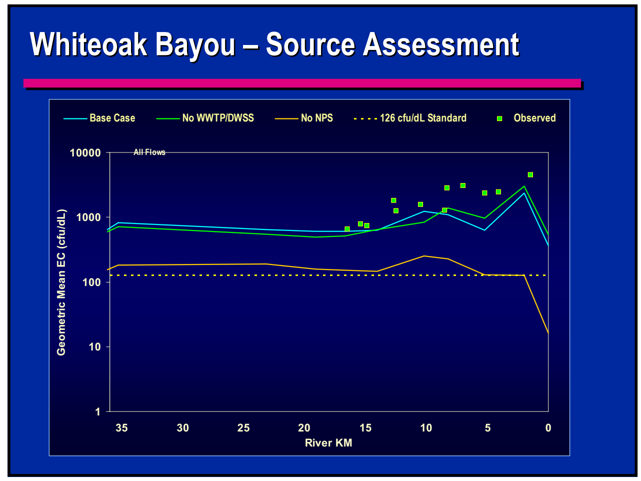
Whiteoak Bayou – Model Results

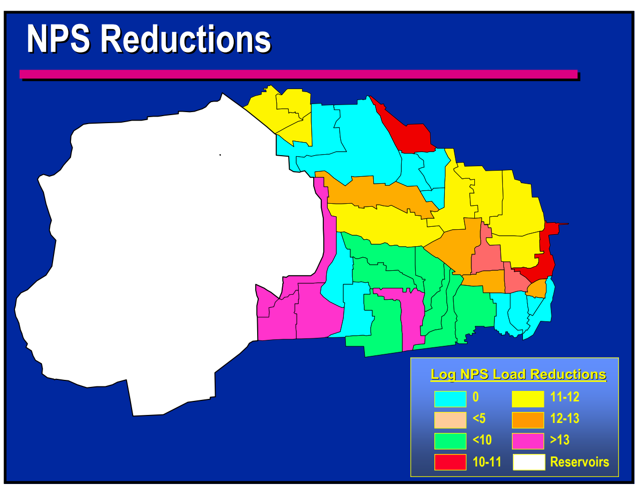


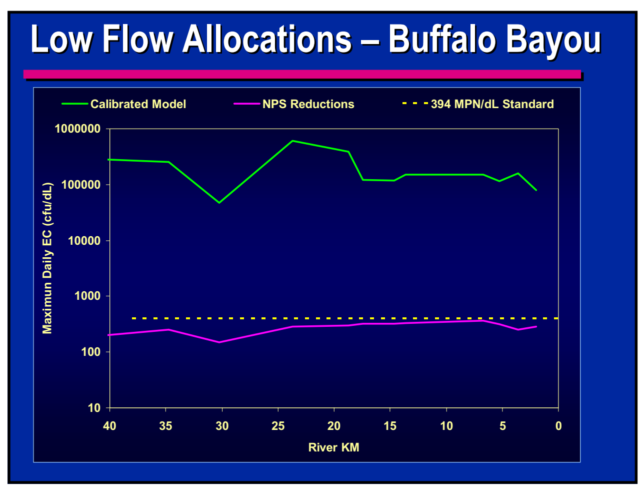
Load Allocation Scenarios

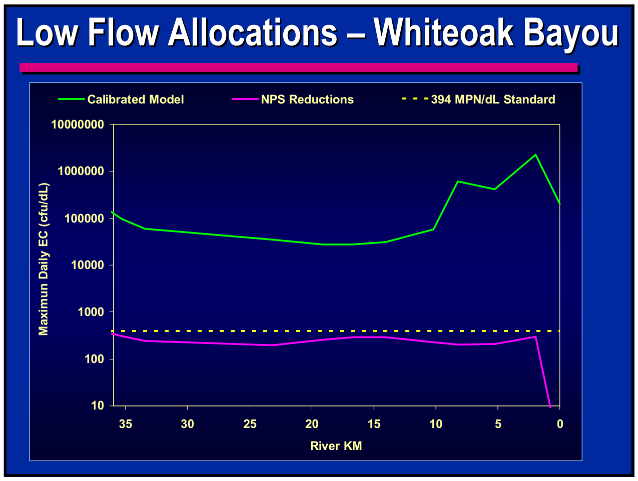
- Eliminate Unpermitted Stormwater EC Discharges
- Eliminate Wastewater Treatment Plant EC Discharges
- Eliminate Wildlife NPS Accumulation of EC
- Eliminate Upstream EC Inflow (Buffalo Bayou)

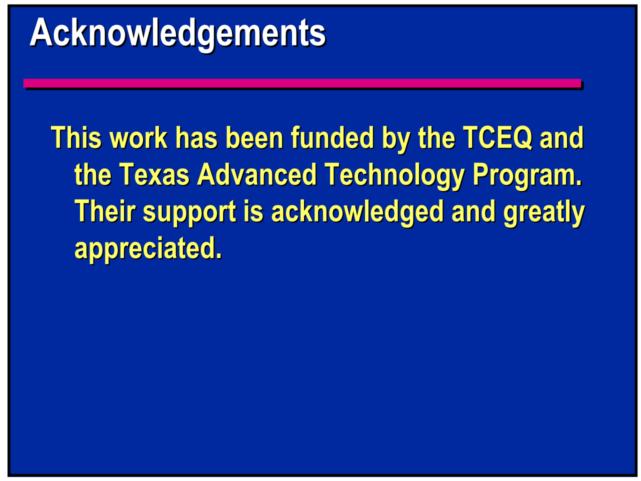

Buffalo Bayou – Source Assessment
Calibrated Model
No Point Sources
Standard - 126 cfu/dL
No NPS
No Upstream
Observed
Geometric Mean EC (cfu/dL)
River KM


Whiteoak Bayou – Source Assessment
Base Case
No WWTP/DWSS
No NPS
126 cfu/dL Standard
Observed
All Flows
Geometric Mean EC (cfu/dL)
River KM


NPS Reductions
Log NPS Load Reductions
0
<5
<10
10-11
11-12
12-13
>13
Reservoirs


Low Flow Allocations – Buffalo Bayou
Calibrated Model
NPS Reductions
394 MPN/dL Standard
Maximun Daily EC (cfu/dL)
River KM


Low Flow Allocations – Whiteoak Bayou
Calibrated Model
NPS Reductions
394 MPN/dL Standard
10000000
1000000
100000
10000
1000
100
10
Maximun Daily EC (cfu/dL)
35
30
25
20
15
10
5
0
River KM


Acknowledgements
This work has been funded by the TCEQ and the Texas Advanced Technology Program. Their support is acknowledged and greatly appreciated.

APPENDIX B

COMPILATION OF WASTEWATER TREATMENT PLANT DATA FOR BIOSOLIDS

Please see the attached CD inside the

folder titled “Appendix B”

APPENDIX C

MASS BALANCE CALCULATION SPREADSHEET

TNRCC ID		Flow Data	Effluent BOD	carbonaceous sludge production	nitrogenous sludge production	inert solids	Digested Sludge	Biosolids Estimated (Mass balance)	Biosolids Reported
		MGD	mg/L	(metric ton/yr)	(metric ton/yr)	(metric ton/yr)		(metric ton/yr)	(metric ton/yr)
				A	B	C	D	E	
10584	BB	2.139	4.243	645.01	9.17	92.97	210.19	462.24	356.30
10706	BB	1.082	3.056	328.26	4.64	47.02	106.96	234.96	284.52
11284	BB	0.606	2.608	184.45	2.60	26.35	60.10	131.96	75.93
11290	BB	2.618	3.424	792.79	11.22	113.77	258.33	567.67	365.57
11486	BB	0.582	2.635	177.10	2.50	25.31	57.70	126.71	118.52
11598	BB	0.691	2.627	210.24	2.96	30.04	68.50	150.42	50.61
11682	BB	0.362	2.543	110.20	1.55	15.74	35.91	78.84	210.54
11836	BB	0.294	3.433	89.01	1.26	12.77	29.00	63.73	52.25
11883	BB	0.485	2.697	147.45	2.08	21.08	48.04	105.50	80.36
11893	BB	1.285	3.051	389.78	5.50	55.83	127.01	279.00	268.24
11969	BB	0.620	2.430	188.64	2.66	26.93	61.46	134.94	234.78
12124	BB	0.307	3.879	92.62	1.31	13.32	30.18	66.35	38.46
12128	BB	0.496	2.138	151.09	2.12	21.53	49.23	108.05	53.60
12222	BB	0.052	2.369	15.84	0.22	2.26	5.16	11.33	7.04
12233	BB	0.001	3.306	0.20	0.00	0.03	0.06	0.14	0.55
12289	BB	0.470	2.273	143.34	2.02	20.44	46.70	102.52	78.64
12298	BB	0.114	2.455	34.75	0.49	4.96	11.32	24.86	11.88
12304	BB	0.407	2.529	123.88	1.74	17.69	40.36	88.62	73.44
12356	BB	0.015	3.200	4.65	0.07	0.67	1.51	3.33	20.30
12427	BB	0.000	2.600	0.01	0.00	0.00	0.00	0.01	0.00
12447	BB	0.307	3.069	93.29	1.32	13.36	30.40	66.77	66.21
12682	BB	0.059	2.014	18.10	0.25	2.58	5.90	12.95	6.64
12685	BB	0.107	3.763	32.40	0.46	4.66	10.56	23.21	15.59
12726	BB	0.320	3.677	96.83	1.37	13.91	31.55	69.35	150.74
12830	BB	0.004	2.500	1.10	0.02	0.16	0.36	0.79	0.00
12841	BB	0.059	2.176	17.86	0.25	2.55	5.82	12.77	16.06
12858	BB	0.016	2.367	4.76	0.07	0.68	1.55	3.41	0.00
13228	BB	0.064	2.658	19.48	0.27	2.78	6.35	13.94	12.17
13245	BB	0.225	2.586	68.45	0.96	9.78	22.30	48.97	4.58
13433	BB	0.026	2.776	7.80	0.11	1.12	2.54	5.58	9.84
13484	BB	0.060	2.783	18.12	0.26	2.59	5.90	12.96	1.77
10495-109	BB	4.347	2.528	1322.79	18.63	188.92	431.00	946.31	575.00
11792-022	BB	0.293	3.111	88.79	1.25	12.72	28.93	63.56	60.58
13172-022	BB	0.370	3.222	112.13	1.58	16.07	36.54	80.27	80.36
11005	WOB	0.182	3.327	55.06	0.78	7.90	17.94	39.42	11.37
11051	WOB	0.034	2.846	10.27	0.14	1.47	3.35	7.35	6.40
11153	WOB	1.436	2.722	436.52	6.15	62.41	142.23	312.34	326.40
11188	WOB	0.264	2.778	80.28	1.13	11.48	26.16	57.45	38.54
11193	WOB	0.410	6.543	122.04	1.76	17.81	39.77	87.67	97.00
11273	WOB	0.455	2.151	138.64	1.95	19.76	45.17	99.14	49.63

TNRCC ID		Flow Data	Effluent BOD	carbonaceous sludge production	nitrogenous sludge production	inert solids	Digested Sludge	Biosolids Estimated (Mass balance)	Biosolids Reported
		MGD	mg/L	(metric ton/yr)	(metric ton/yr)	(metric ton/yr)		(metric ton/yr)	(metric ton/yr)
11538	WOB	0.967	2.324	294.49	4.14	42.01	95.95	210.63	152.59
11563	WOB	0.739	2.191	225.21	3.17	32.11	73.38	161.05	152.86
12132	WOB	0.040	2.821	12.07	0.17	1.73	3.93	8.64	0.57
12139	WOB	0.020	2.668	5.95	0.08	0.85	1.94	4.26	6.34
12443	WOB	0.002	4.095	0.53	0.01	0.08	0.17	0.38	1.09
12552	WOB	0.007	2.721	2.17	0.03	0.31	0.71	1.55	2.91
12681	WOB	0.174	3.383	52.70	0.75	7.56	17.17	37.73	40.20
12714	WOB	0.137	2.615	41.59	0.59	5.94	13.55	29.76	19.51
12795	WOB	0.254	3.077	77.03	1.09	11.03	25.10	55.14	47.06
13623	WOB	0.050	2.892	15.03	0.21	2.15	4.90	10.76	28.84
13689	WOB	0.376	3.222	113.98	1.61	16.34	37.14	81.60	84.89
10495-076	WOB	9.868	2.319	3006.17	42.29	428.87	979.47	2150.13	4118.00
12552-002	WOB	0.004	5.000	1.30	0.02	0.19	0.42	0.93	2.54

$$A=\frac{P_{xc}}{0.85}=\frac{Y_{c,obs}}{0.85}*Q*(BOD_0-BOD_e)*\frac{1kg}{10^3 g}$$

$$B=\frac{P_{xn}}{0.85}=\frac{Y_{n,obs}}{0.85}*Q*(N_0-N_e)$$

$$C=Q*(TSS_0-VSS_0)$$

BOD_0	190
BOD_e	Effluent BOD
N_0	25
N_e	3
TSS_0	210
VSS_0	85% of TSS_0
Solids Reduction Rate	42%

D= Solids Reduction Rate of Digester *(Carbonaceous +Nitrogenous Sludge into the digester)

E=A+B+C-return activated sludge (0.1*(A+B+C))-D

APPENDIX D

ADDING A DIVERSION POINT AS AN ADDITIONAL EXIT IN HSPF

This brief Appendix describes the methodology used in Chapter 4 to modify the existing HSPF models for Buffalo and Whiteoak Bayous to incorporate diversions.

1. Add additional exit(s) to the RCHRES within the [NEXITS] block (located within the [GEN-INFO] block).
2. Add [ODGTFG] component for the outflow demand required at each exit and add a function number for each possible exit (both of these variables are located within the [HYDR-PARM1] block).
3. Add WDM link information for each diversion within the [EXT SOURCES] block; Ex. "WDM3 539 DIVER ENGLZERO SAME RCHRES 39 EXTNL OUTDGT 1"
4. Add WDM information for the diversion to the [EXT TARGETS] block. Make sure that information has been included for the flow data, as well as, the dissolved and sediment-associated bacteria, if included in the model.

   Ex. "RCHRES 39 HYDR OVOL 2 1 WDM 1 404 DIVER ENGL AGGR REPL"
5. Create a Mass-Link Block to route flow from each exit to its intended target location. This should only be done for those exits that direct water to a modeled target location. The mass-link must be designed to account for the flow of bacteria to each subsequent RCHRES downstream.
6. In the [SCHEMATIC] block, the mass-link number created in step 5 must be called upon to direct flow from each particular exit to each intended RCHRES.
7. Build a source WDM time series to store the diversion amounts for each scenario.
8. Build a target WDM for each output time series that is required to be output to a WDM file.

APPENDIX E

SELECTED ANNOTATED BIBLIOGRAPHY OF SOILS AND BACTERIA

Buckley, R., Clough, E., Warnken, W, Wild, C. 1998. *Coliform Bacteria in Streambed Sediments in a Subtropical Rainforest Conservation Reserve*. Water Res. (G.B.), 32, 1852.

Buckley, et al., found significantly higher concentrations of bacteria in streambed sediments in a minimally disturbed conservation reserve in Queensland, Australia, during the dry season compared to the wet season. *Klebsiella, Enterobacter, Escherichia, Acinetobacter, Citrobacter, Serratia, Providencia, Morganella, Plesiomonas,* and *Aeromonas* were isolated from sediment samples.

Fish, J. T., Pettibone, G. W. 1995. *Influence of Freshwater Sediment on the Survival of Escherichia coli and Salmonella sp. as Measured by Three Methods of Enumeration*. Lett. Appl. Microbiol., 20, 277.

Both *Salmonella* and *E. coli* survived at least 28 days in microcosms containing autoclaved water and freshwater sediments. There was no difference between microbial numbers using direct counts, direct viable counts, and standard plate counts, nor were there differences in the number of *E. coli* determined by plate counts on selective or non-selective media.

Oshiro, R., Fujioka, R. 1995. *Sand, Soil and Pigeon Droppings: Sources of Indicator Bacteria in the Waters of Hanauma Bay, Oahu, Hawaii*. Water Sci. Tech., 31, 251.

Found that contamination of marine environments by birds, specifically beach sand contaminated with pigeon feces, correlated with increased numbers of fecal coliforms in the water.

Sjogren, R. E. 1994. *Prolonged Survival of an Environmental Escherichia coli in Laboratory Soil Microcosms*. Water, Air, Soil Pollut. (Neth.), 75, 389.

High levels of *Escherichia coli* were capable of prolonged survival in laboratory soil microcosms indicating that land application of improperly disinfected wastewater sludges could result in contamination with these organisms.

Tetsushi, Watanabe, Teruhisa, Hirayama. 2001. *Genotoxicity of Soil.* Journal of Health Science, Volume 47, Number 5, Page 433-438, October.

A review of the literature published on the genotoxicity of soil is presented in this report. Subheadings of the report include outlines of genotoxicity assays that have been used to examine the soil samples and methods commonly used to prepare soil samples for genotoxicity assay, and a review of the genotoxicity of soil. Soil has been grouped according to potential sources of pollution, e.g., industrial activity, agricultural practices, and motor vehicles. The possible causes of the genotoxicity of the soil are also mentioned.

University of Adelaide. 2003. *Occupational Hazard Information Sheet: Soils and Potting Mixes.* Human Resources Website, accessed May 14, 2003.

http://www.adelaide.edu.au/hr/ohs/hazinfo/soil.html

As soils may contain a large variety of micro-organisms which have come from a range of sources it is possible for diseases to be transmitted. Organisms of particular concern are the tetanus bacillus, which causes tetanus, and legionella pneumophila, which causes legionnaire's disease. Other diseases can also be spread via soil.

National Institute of Occupational Safety and Health. 1997. *HISTOPLASMOSIS: Protecting Workers at Risk.* Publication No. 97-146, September.

http://www.cdc.gov/niosh/hi97146.html

Histoplasmosis is an infectious disease caused by inhaling the spores of a fungus called Histoplasma capsulatum. Histoplasmosis is not contagious; it cannot be transmitted from an infected person or animal to someone else.

H. capsulatum grows in soil and material contaminated with bat or bird droppings. Spores become airborne when contaminated soil is disturbed. Breathing the spores causes infection. The disease is not transmitted from an infected person to someone else.

Bolton, F. J., Surman, S. B., Martin, K., Wareing, D. R., Humphrey, T. J. 1999. *Presence of Ampylobacter and Salmonella in Sand from Bathing Beaches*. Epidemiol. Infect., 122, 1, 7.

Campylobacter spp. were isolated from 50% of samples from non-EEC standard beaches and 40% from EEC standard beaches in a study by Bolton, et al. (1999). The prevalence of *Campylobacter* spp. was greater in wet sand from both types of beaches but, surprisingly, more than 30% of samples from dry sand also contained these organisms. The major pathogenic species *C. jejuni* and *C. coli* were more prevalent in sand from non-EEC standard beaches indicating that *Campylobacter* strains associated with human infections are frequently found in sand on bathing beaches.

Bruins, Mark R., Kapil, Sanjay, Oehme, Frederick W. 2000. *Pseudomonas pickettii: A Common Soil and Groundwater Aerobic Bacteria with Pathogenic and Biodegradation Properties.* Ecotoxicology and Environmental Safety, Volume 47, Number 2, Page 105-111, October.

Pseudomonas pickettii is an aerobic, non-fermentative, gram-negative rod-shaped, bacterium that has been isolated from soil, water, humans, and recently the bovine intestinal tract. It belongs to the rRNA group II of the genus Pseudomonas and has three biovars: Va-1, Va-2, and biovar 3/thomasii. P. pickettii can cause pneumonia, meningitis, endocarditis, and osteomyelitis in humans. It frequently is associated with nosocomial infections that often are linked to contaminated injectable solutions. P. pickettii exhibits remarkable ability to degrade a variety of toxic compounds such as chlorophenols, aromatic hydrocarbons, 2,4-dichlorophenoxyacetic acid, and pentacyclic triterpeniod compounds. The genes that encode for these properties are chromosome- and plasmid-associated. Strains of the organism also have demonstrated resistance to heavy metals, such as cadmium, copper, and zinc. This species can survive in a

nutrient-poor environment and use a variety of toxic compounds as carbon and energy sources, making it an ideal candidate for study in the biodegradation of toxic compounds found in wastewater and soils.

Centers for Disease Control and Prevention. 1988. *Epidemiologic Notes and Reports Multistate Outbreak of Sporotrichosis in Seedling Handlers Morbidity and Mortality Weekly Reports;* October, 37 (4Z) 652-3.

http://www.cdc.gov/mmwr/preview/mmwrhtml/00001295.htm

Between April 23 and June 30, 1988, 84 cases of cutaneous sporotrichosis occurred in persons who handled conifer seedlings packed in Pennsylvania with sphagnum moss that had been harvested in Wisconsin. An outbreak-related case was defined as physician-diagnosed sporotrichosis in a person who had handled seedlings and/or moss. Confirmed cases occurred in 14 states: New York, 29 cases; Illinois, 23; Pennsylvania, 12; Ohio, 5; Wisconsin, 3; Connecticut, North Carolina, and Vermont, 2 each; and Indiana, Iowa, Massachusetts, Michigan, New Hampshire, and Virginia, 1 each. Each of these persons handled seedlings from April 4 to May 16; symptoms developed between April 23 and June 30.

Olsen, A. 2003. *Experience with School-Based Interventions Against Soil-Transmitted Helminths and Extension of Coverage to Non-Enrolled Children*. Acta Tropica (ACTA TROP.) (Netherlands), May 1, 86/2-3 (255-266).

This paper reviews the experience with school-based interventions against soil-transmitted helminths with regard to reduction in prevalence, intensity of infection and morbidity. It also examines the existing experience with coverage of school-based programs to non-enrolled children. However, as this experience is limited, the paper also seeks to give an overview of the need for school control programs to include other segments of the community. The experiences from the programs indicate that treatment should be performed twice or thrice yearly without prior diagnosis, and should be school-based and involving schoolteachers assisted by health staff, if possible. The drugs of choice are a single dose of 400 mg albendazole or 500 mg mebendazole. If intensities of Trichuris trichiura or hookworm infections are high,

a double or triple dose of one of these drugs could be considered to maximise reduction in intensities. For the benefit of growth and iron status, it should be considered to supplement with iron and other micronutrients. School-based programs should include non-enrolled school-age children and pre-school children, and the system of having "treatment days" at school where these groups are invited for treatment seems to be a promising strategy. While antenatal clinics have been involved in the anthelminthic treatment of pregnant women, they have not covered non-pregnant adolescent girls and women. These could be offered treatment through the "treatment days" at school mentioned earlier. (^53 References)

APPENDIX F

BACTERIA SOURCE TRACKING

Included in this appendix are several items related to the bacteria source tracking analysis. The items included in the appendix and on the attached CD are listed below.

- A sample print out from the MIS can be found as Figure F.1. The entire MicroStation MIS set is presented in the attached CD in the Appendix F folder wtihin a folder labeled "Hou Biolog fecal." Hard copies are stored at Texas A&M University-Corpus Christi.
- A sample Gel image is include as Figure F.2.
- A sample print-out showing the BIOMIC results for one isolate is presented as Figure F.3
- The BIOMIC databases are stored on the attached CD-ROM under two folders "Hou ARA RIS" and "Hou ARA Zone" - Resistant:Intermediate:Susceptible and zone diameters. The complete set of print-outs is stored at Texas A&M University-Corpus Christi.
- Discriminant analysis tables are included in a separate section titled "Discriminant Analysis Tables" and on the enclosed CD-ROM in the folder "Discriminant Analysis in Word". SPSS® data is included as a separate folder ("SPSS Data") on the CD-ROM.

Figure F.1

Sample Print Out from the MicroStation Microbial Identification System (MIS)

APPENDIX G

ADDITIONAL ANALYSIS OF TIME VARYING FLOWS

The goal of developing a statistical pattern from 2001-2003 daily WWTP time series data was shown to be unviable, as there was no temporal pattern common to all six City of Houston waste water treatment plants. This appendix is designed to present the tests used and analysis of those tests to reach that conclusion. There was, however, a frequency pattern which may be used in the future for further analysis of the discharge flow.

G.1 Autocorrelations

An autocorrelation test is a measure of the relationship between points in a time series by using a lag of the data to itself. If a lag of the data compared to the actual data is similar, then the data are said to be autocorrelated. Thinking about this in an excel spreadsheet, one would have the original series of data points in column one. For the first lag, the data would be moved down one row and lined up in column two next to the original data. Patterns between column one and two would then be compared. If the data are similar from column one to column two, then data would be said to be autocorrelated. This could indicate a pattern in the data and is a good place to begin when looking for temporal patterns. Plots of autocorrelation were considered to check for non-randomness in the data.

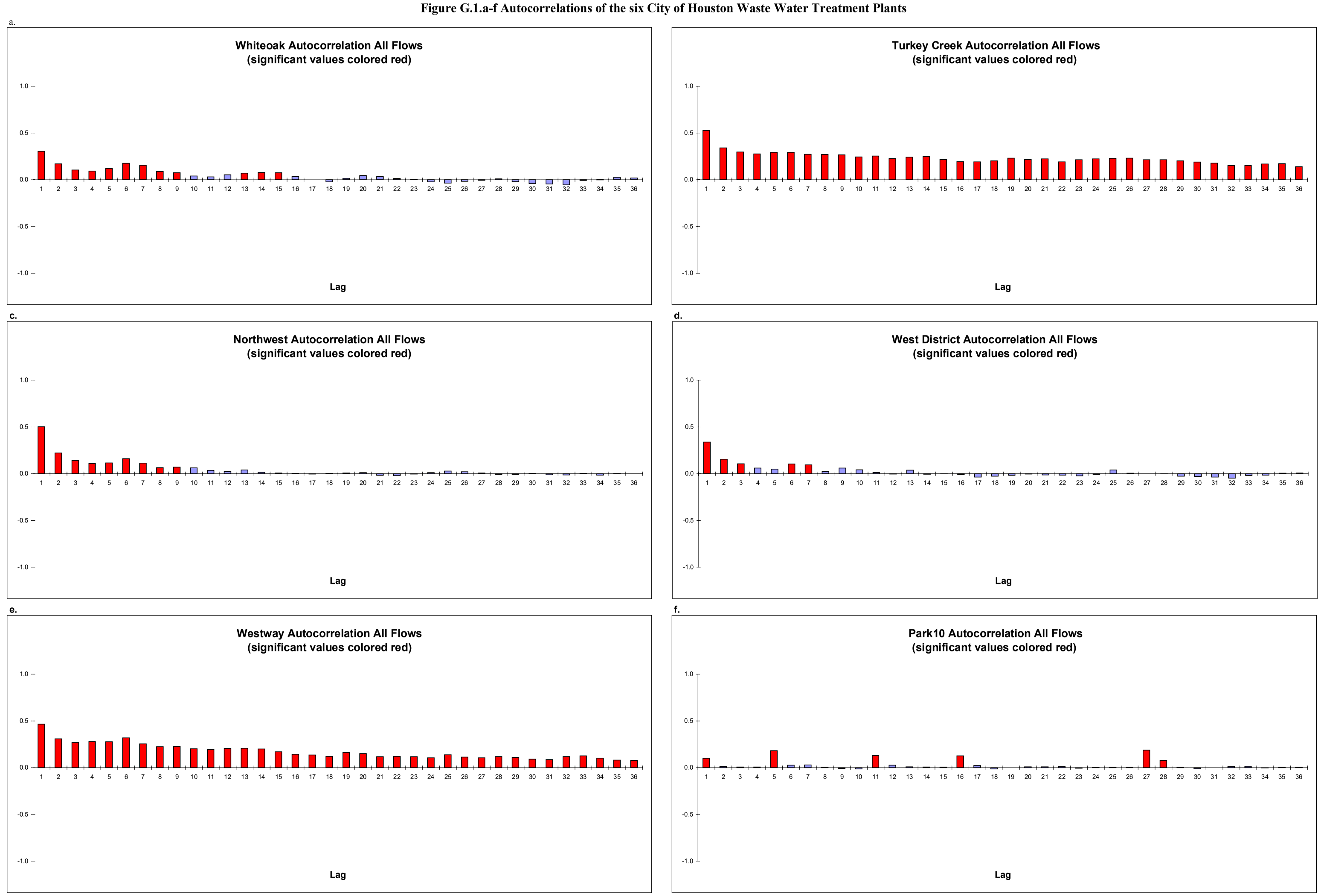
To determine whether or not an autocorrelation value was significant, the standard error was calculated for each WWTP. Any value greater than twice the standard error was considered significant and indicated an autocorrelation in the data. The equation to determine standard error, under the assumption of randomness, is

$$\frac{1}{\sqrt{T}}$$

where T is equal to the total number of observations in the series.

The values colored in red on the graphs in Appendix Figure G.1 indicate which autocorrelations were significant. Table G.1 shows the standard error and twice the standard error which is the measure of significance. Note that the standard error is the same for all plants except Northwest because it is based on the number of total observations.

Figure G.1.a-f Autocorrelations of the six City of Houston Waste Water Treatment Plants



Appendix G Table G.1. WWTPs, Number of Observations (T), and Standard Error

WWTP	**WQ0010495**	**T**	**Std. Error**	**2 Times Std. Error**
White Oak	99	1125	0.0298	0.0596
Northwest	76	1030	0.0312	0.0623
Westway	139	1125	0.0298	0.0596
Turkey Creek	109	1125	0.0298	0.0596
Park Ten	135	1125	0.0298	0.0596
West District	30	1125	0.0298	0.0596

Using a total of thirty-six lags, to check for relationships between months, it was possible to see that with a lag of only one or two, there was a relationship between the data points. At Turkey Creek and Westway the data appear to be related to each other over time, as all lags are significantly autocorrelated. This could indicate a pattern in the data. At Park Ten, however, the data did not appear to be related at all. Whiteoak and Northwest appear to have data that are related as far as nine days apart, and West District three days. All plots are in Appendix G Figure G.1.

G.2 Runs test

The runs test for randomness is formal test which checks for random behavior within a data set. The test checks for patterns of above and below a mean or median, which is called a base level. A series of values above or below the base level indicates a run. The null hypothesis is that if there are too many or too few runs, then the data are not random. If the null hypothesis is rejected, then the data are random.

This test was completed to double check the results from the autocorrelations and examine the dataset for any other patterns not found in the autocorrelations test. The median was used as the base measure, as opposed to the mean because the data are not normally distributed (the original flow values were used in this analysis). Looking at Appendix G Table G.2, we can see that all of the data from all of the plants are random. E (R) is the number of runs expected under an assumption of randomness, and the Z-value is a measure of how many standard errors the observed number of runs is below the number of runs. The p-value gives the significance of the Z-value. The low p-value for each plant indicates that the null hypothesis of not-random must be rejected, therefore the data ARE random. This is interesting because some of the autocorrelations appeared to show a relationship when the data were lagged by a few days. However, the runs test is a formal test for randomness, while the autocorrelation procedure was informal. Therefore, the results of this test are more reliable and will be considered more conclusive than the autocorrelation results.

Appendix G Table G.2 Results of Runs Test for Randomness at Six COH WWTPs

Plant Name	**WhiteOak**	**Northwest**	**West Way**	**TurkeyCreek**	**WestDistrict**	**ParkTen**
Permit No WQ0010495-	99	76	139	109	30	135
No. of obs	1125	1020	1125	1125	1125	1125
No. above cutoff	563	516	563	506	568	564
No. below cutoff	562	514	562	506	557	561
No. of runs	426	231	284	240	342	396
E (R)	563.50	516.00	563.50	507.00	563.45	563.50
Stdev(R)	16.76	16.04	16.76	15.90	16.76	16.76
Z-value	-8.20	-17.77	-16.67	-16.79	-13.21	-9.99
p-value (2-tailed)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

G.3 Regressions of Rainfall and Flow Data

According to previous studies, rainfall and WWTP discharge flows should be highly correlated. The expected result of completing a regression analysis between WWTP discharge flows and rainfall would be a high correlation. To check this relationship, a regression analysis was performed for all plants using daily flow averages and rainfall amounts from the nearest rainfall gauge. Figure G.2 shows a map of the six COH WWTPs and nearest rain gauges. Table G. 3 gives a summary of WWTP name and nearest rain gauge. As explained in section 10.1.2, in order to assure accurate results, the data were checked for normality prior to any regression analysis.

The hypothesis of WWTP discharge volume dependence on rain was tested by examining the data in two different ways. First, to check for a general correlation between rainfall and

Table G.3 Rain Gauges Assigned to Each Plant

Permit #	Name	Rain Gauge
WQ0010495-030	WEST DISTRICT	2270
WQ0010495-076	NORTHWEST	575
WQ0010495-099	WHITE OAK	540
WQ0010495-109	TURKEY CREEK	3680
WQ0010495-135	PARK TEN	3690
WQ0010495-139	WESTWAY UD	580[1]

[1] Although 3560 is the closest rain gauge, the data quality at this site are very poor and therefore 580 was employed instead.

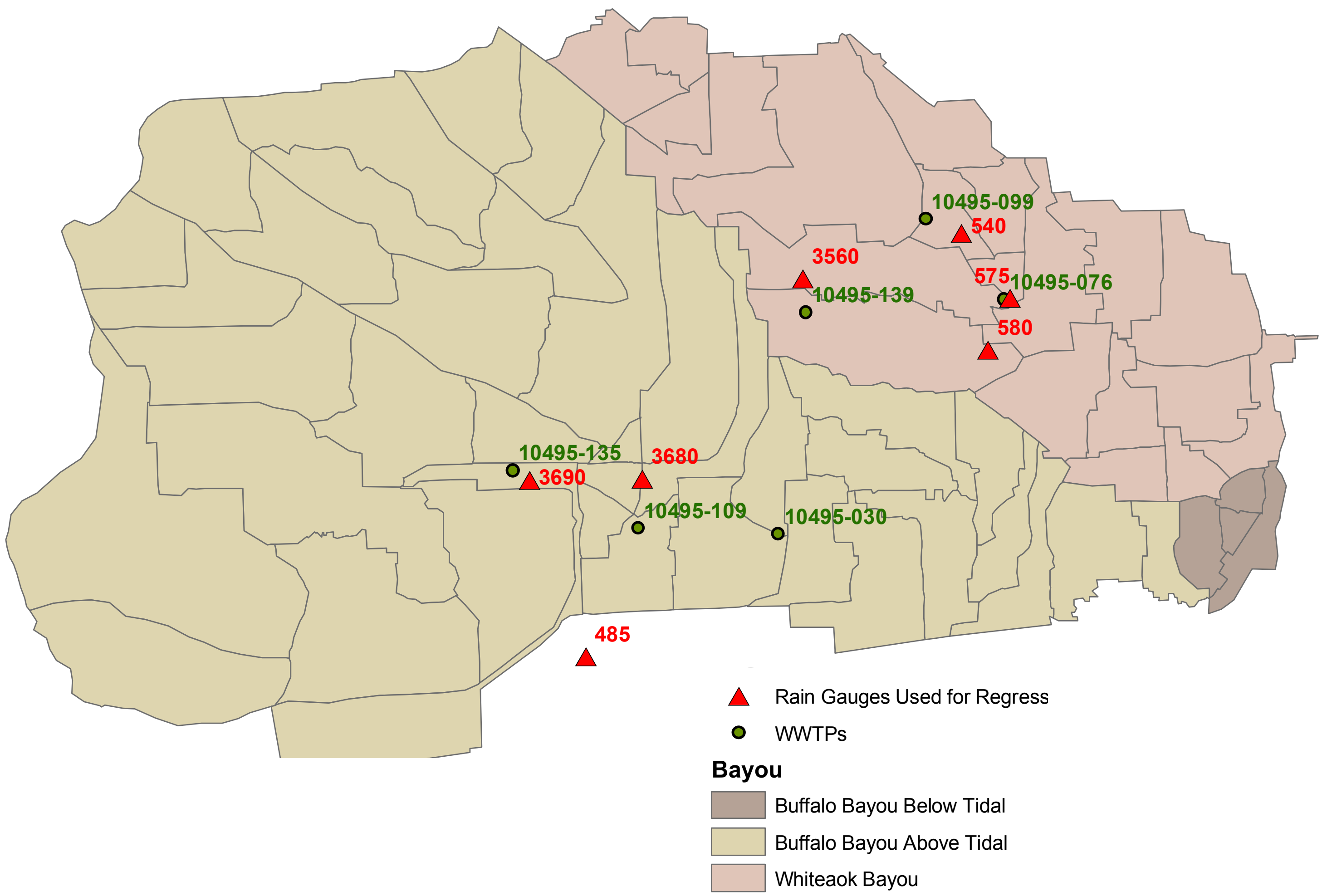


Figure G.2
Locations of Rainfall Gauges in Relation to COH WWTPs

Table G.3 Summary of Plant Data

Plant Name	**WhiteOak**	**Northwest**	**West Way**	**TurkeyCreek**	**WestDistrict**	**ParkTen**
Permit No WQ0010495-	99	76	139	109	30	135
No. of obs	1125	1030	1125	1125	1125	1125
No. above cutoff	563	516	563	564	568	564
No. below cutoff	562	514	562	561	557	561
No. of runs	426	231	284	286	342	396
E (R)	563.50	516.00	563.50	563.50	563.45	563.50
Stdev(R)	16.76	16.04	16.76	16.76	16.76	16.76
Z-value	-8.20	-17.77	-16.67	-16.55	-13.21	-9.99
p-value (2-tailed)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

WWTP flows, all available log-transformed data for both variables were considered. Then, to check for a higher correlation between rainfall and WWTP flow on days when there was rain, flows from WWTPs on days when it rained were regressed with the rainfall amounts, again the data was log-transformed.

The results of the regression analysis are displayed in Appendix G Table C.4. The scatter plots for White Oak are displayed in Figure G.3, with the regression line superimposed. The scatter plots of flows and rainfall amounts can be found in Figure G.4, with a linear representation of the regression superimposed. The R^2 values and formulae for the regression are also shown on each graph. According to the plots, rainfall is generally not a good predictor of WWTP flows in this case. The highest R^2 value is found at West District (WQ0010495-030) when the analysis compared only flow data for days when it rained with the rain data from those days. The R^2 value of 0.59 when only rainfall days are considered is higher than would be expected, but still leaves 41% of the variability to be explained. Also, by looking at the scatter plot, it is possible to see that although the points for this plot follow the regression line better than all other plots, there is a large clump near zero. This suggests that the residuals of the regression are not random and the results should be interpreted with caution. At Northwest plant (WQ0010495-030) the value is a bit lower with an R^2 value of 0.56. This still leaves 44 percent of the variability to be explained. The other plants show R^2 values even lower, which leaves too much variability unexplained. The conclusion is that rainfall is not generally a good indicator of WWTP discharge flows because too much variability is left unexplained. Table G.3 gives a summary of the regression results.

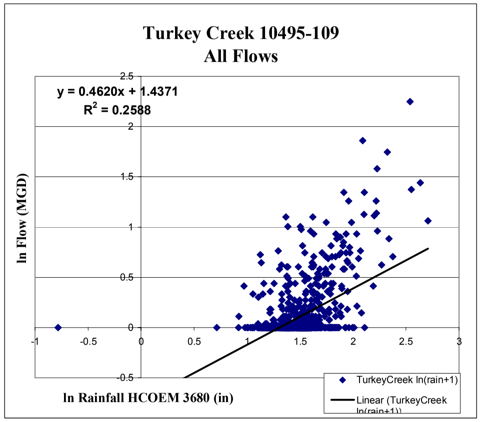
Table G3, R-squared values for All-rain/All-flow and

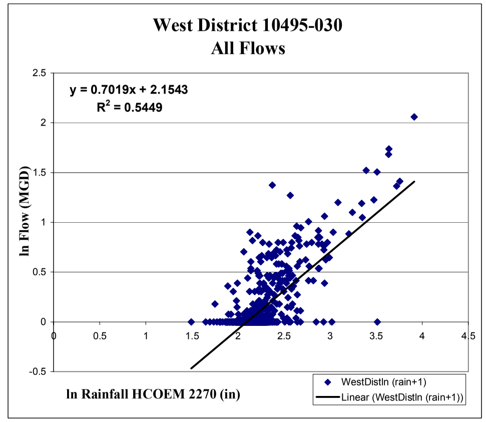
Rain-day flow/ Rain-Amount

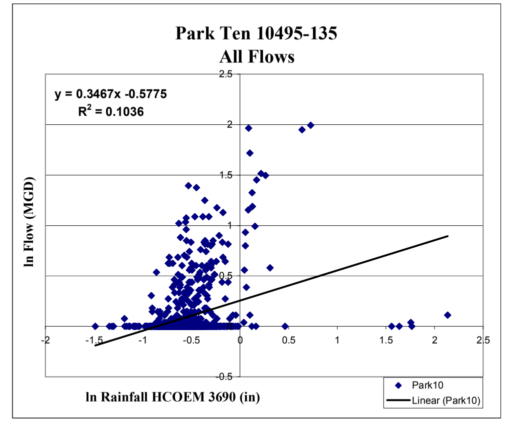
	Whiteoak	Northwest	Westway	Turkey Creek	West District	Park Ten
Permit Number 10495-	099	076	139	109	030	135
All Flow R^2	0.19*	0.5*	0.27*	0.26*	0.55*	0.1*
Rain only R^2	0.24*	0.56*	0.36*	0.34*	0.59*	0.15*

* indicates significant value

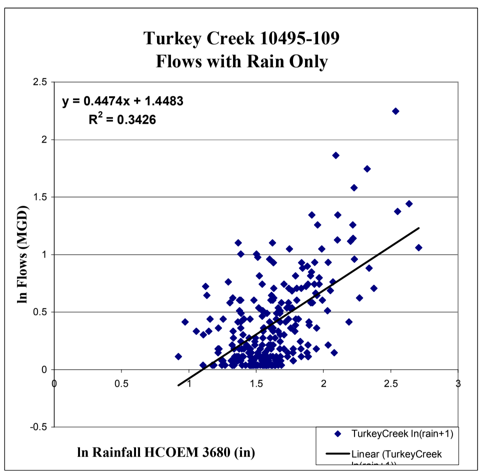
Regressions of Buffalo Bayou log-Transformed City of Houston Waste Water Treatment Plants All Flows with log-Transformed All Rainfall Data

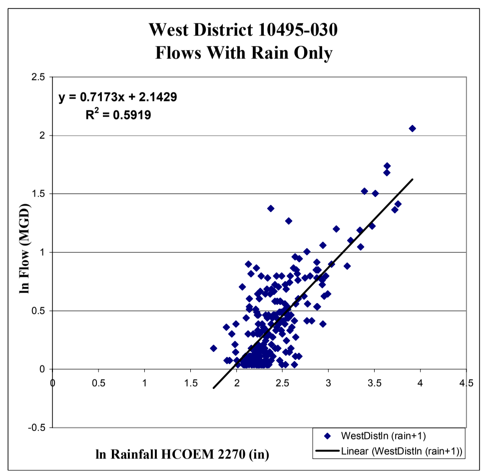






Regressions of Buffalo Bayou log-transformed City of Houston Waste Water Treatment Plant Flows with log-transformed Rainfall Data for Days with Rain Only





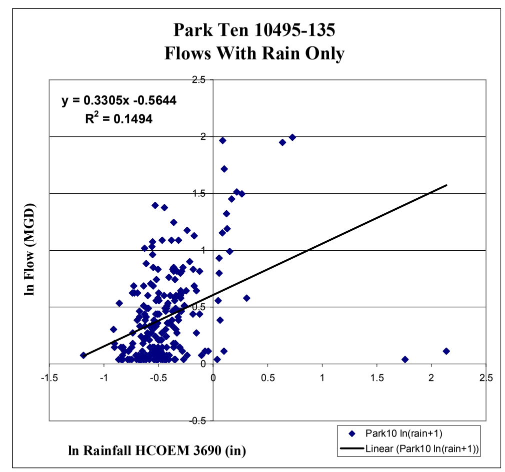


Figure G.3. Scatter plots of log-transformed flow and rain data with linear regression line superimposed

G.4 Frequencies of Above and Below Yearly Average Flow

The last method which was attempted to find a repeatable pattern in the WWTP flows was frequency. This is not a temporal pattern, which was the goal of the analysis, but a frequency pattern. The yearly average was considered as the baseline, and the number of times that flow exceeded the yearly average was calculated for each month at each plant. The years 2001-2003 were included, but no data from 2004 as there were only two to three months of data for some plants but not all. There is a definite pattern followed by four of the six plants, and some seasonality can be seen as well with the lowest flows in May, June, or July and the highest flows in December, January, and February for all plants excepting Park Ten. Table G.5 shows the frequency results, Figures G.5.a-c show graphs of each year, and all years together can be seen in Figure G.6. It is important to note that there was a dramatic decrease in flows at the Turkey Creek WWTP in 2003. This may be the reason that that plant exhibits so many days above the yearly average for the later part of that year. The decrease in flow happened in the second half of the year, which most likely decreased the yearly average, thereby resulting in an unusually high frequency of over-average flows. The link that ties the plants together is still under investigation for possible future use in discharge flow predictions.

Table G.5. Frequency Above Yearly Mean by Month, 2001-2003

Above Yearly Average Flow Frequency 2001

2001 Month	Northwest	WhiteOak	TurkeyCreek	Park Ten	WestWay	WestDist
January						
February						
March	11	16	14	19	4	12
April	7	9	4	13	2	5
May	3	6	7	15	4	3
June	11	8	9	20	25	10
July	2	4	2	21	29	1
August	4	10	6	27	6	7
September	8	15	17	19	5	11
October	5	10	9	7	5	6
November	4	4	4	5	1	3
December	14	20	9	4	5	11
Total Days	69	102	81	150	86	69

Above Yearly Average Flow Frequency 2002

2002 Month	Northwest	WhiteOak	TurkeyCreek	Park10	WestWay	WestDist
January	14	7	3	4	7	11
February	9	6	2	5	3	5
March	2	9	4	5	7	9
April	7	14	8	8	15	16
May	2	5	2	15	5	2
June	3	6	7	17	3	11
July	5	11	8	20	4	6
August	5	12	20	23	7	3
September	3	11	16	23	10	3
October	13	14	19	23	15	16
November	10	13	18	15	11	10
December	18	17	5	9	21	12
Total Days	91	125	112	167	108	94

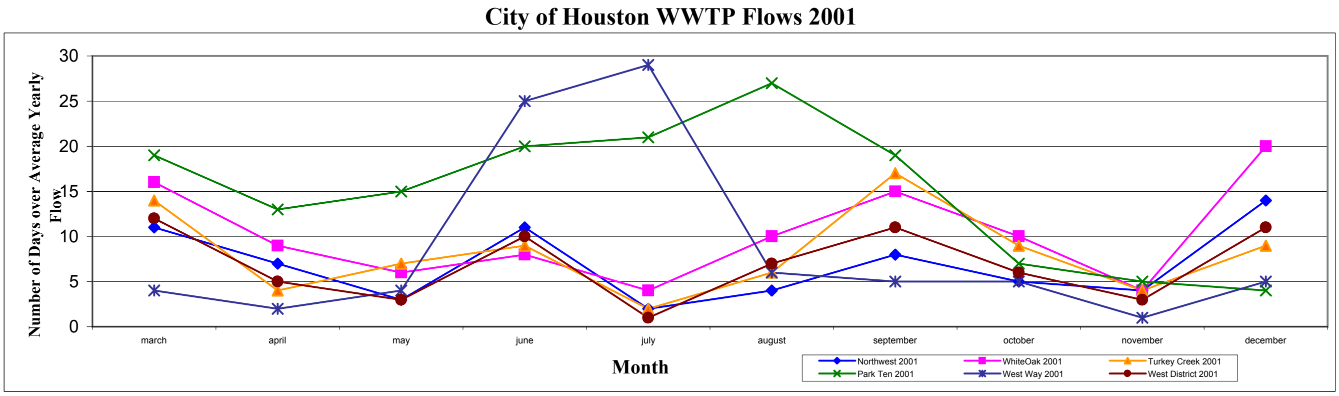
Above Yearly Average Flow Frequency 2003

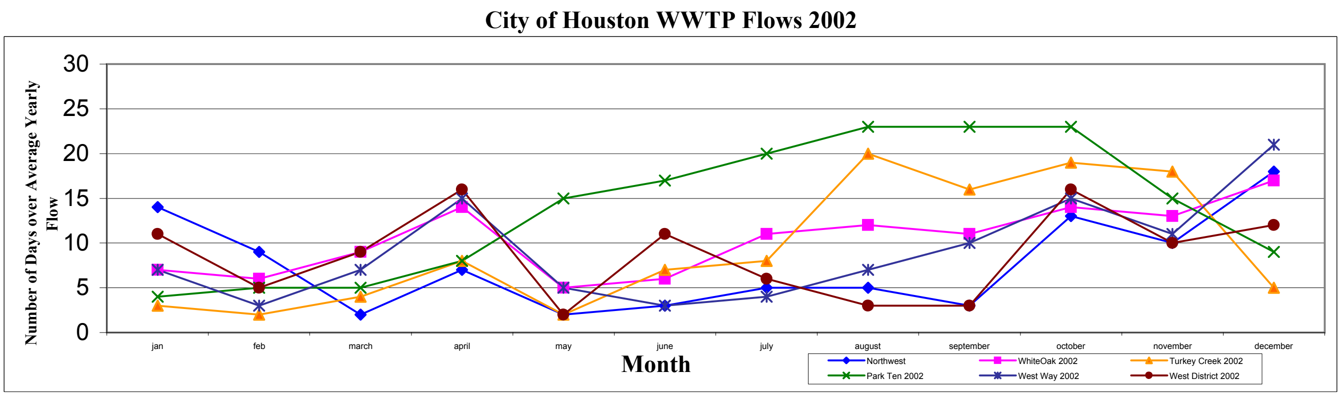
2003 Month	Northwest	WhiteOak	TurkeyCreek	Park10	WestWay	WestDist
January	13	10	9	4	4	5
February	28	24	15	5	17	18
March	24	19	3	5	26	10
April	2	8	0	5	10	5
May	1	1	1	3	9	0
June	5	9	5	4	7	5
July	5	9	22	12	17	11
August	1	8	23	11	4	12
September	7	13	19	7	6	14
October	3	7	14	2	7	6
November	4	11	20	5	12	8
December	2	6	11	4	2	5
Total Days	95	125	142	67	121	99

Table G.6 Frequency Above Yearly Mean for All Years Together

Month	Northwest	WhiteOak	TurkeyCreek	ParkTen	WestWay	WestDist
January						
February						
March	11	16	14	19	4	12
April	7	9	4	13	2	5
May	3	6	7	15	4	3
June	11	8	9	20	25	10
July	2	4	2	21	29	1
August	4	10	6	27	6	7
September	8	15	17	19	5	11
October	5	10	9	7	5	6
November	4	4	4	5	1	3
December	14	20	9	4	5	11
January	14	7	3	4	7	11
February	9	6	2	5	3	5
March	2	9	4	5	7	9
April	7	14	8	8	15	16
May	2	5	2	15	5	2
June	3	6	7	17	3	11
July	5	11	8	20	4	6
August	5	12	20	23	7	3
September	3	11	16	23	10	3
October	13	14	19	23	15	16
November	10	13	18	15	11	10
December	18	17	5	9	21	12
January	13	10	9	4	4	5
February	28	24	15	5	17	18
March	24	19	3	5	26	10
April	2	8	0	5	10	5
May	1	1	1	3	9	0
June	5	9	5	4	7	5
July	5	9	22	12	17	11
August	1	8	23	11	4	12
September	7	13	19	7	6	14
October	3	7	14	2	7	6
November	4	11	20	5	12	8
December	2	6	11	4	2	5

Figure G.5 Plot of Frequency Above Yearly Average Years 2001-2003





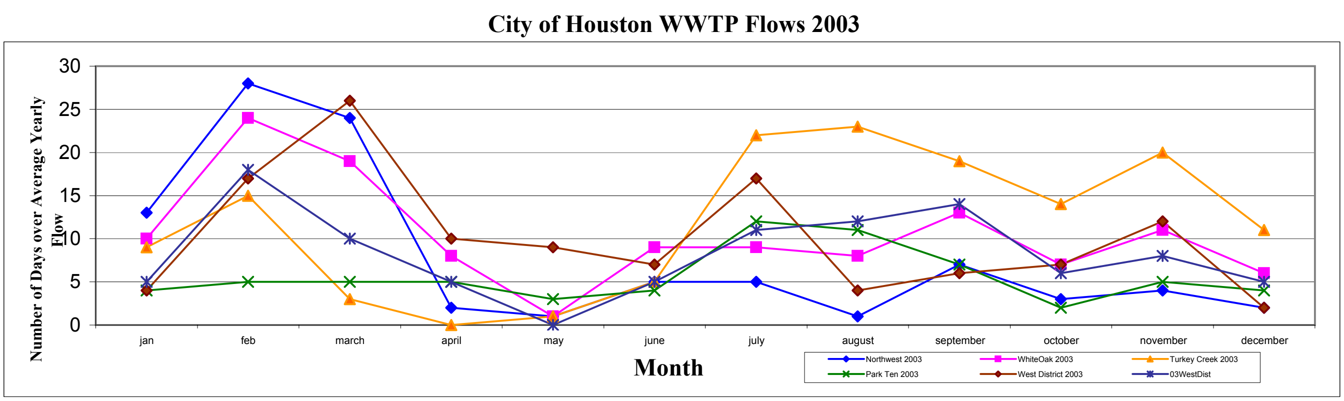
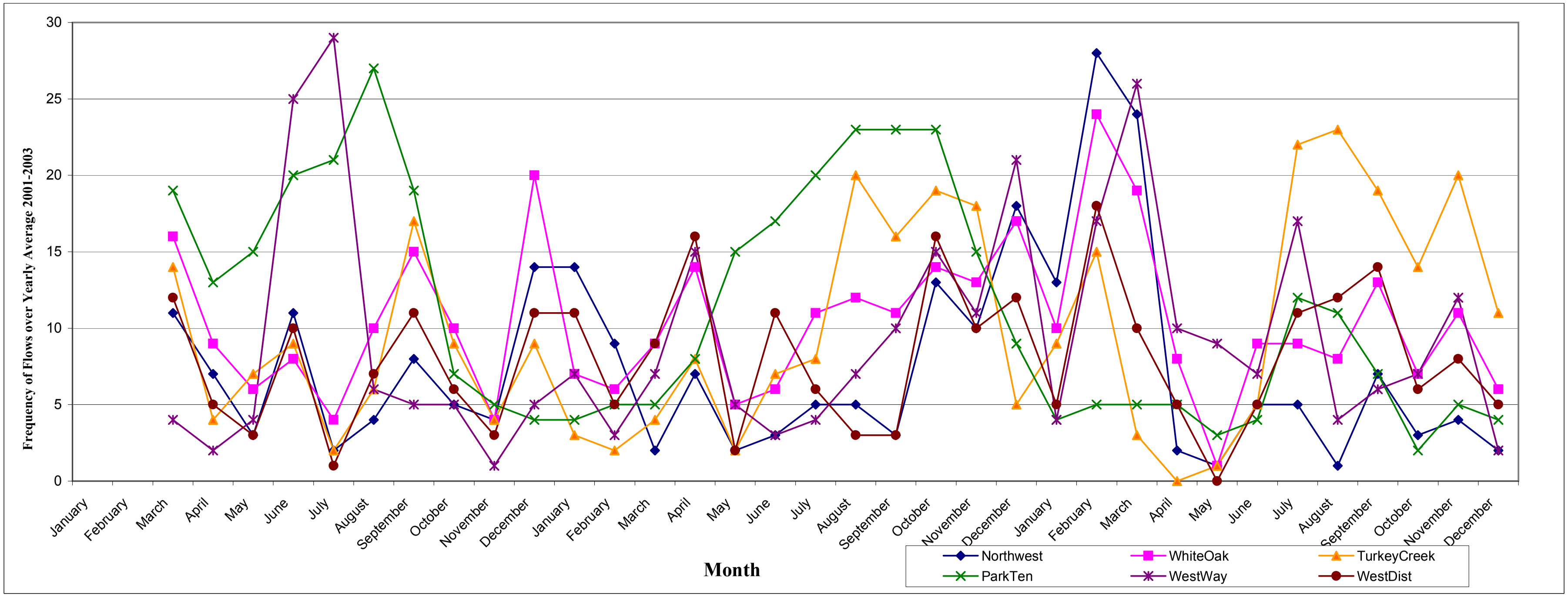


Figure G.6 Number of Days Above the Yearly Average for the Years 2001-2003 for Six City of Houston WWTPs



APPENDIX H

TIME-VARYING FLOW FOR ALL WWTPS IN THE STUDY AREA

Please see the attached CD inside the

folder titled "Appendix H"

APPENDIX I

QUALITY ASSURANCE PROJECT PLAN

Please see the attached CD inside the

folder titled “Appendix I”